GE 136A: Fall 2025 Field Guide

San Bernardino Mtns & Mojave Desert

A view of one of the many hot springs we will hike to. The springs are in the rain shadowed desert foothills of the San Bernardino Mountains on the Deep Creek fork of the Mojave River. They are in a large granitic bouldered riparian zone, surrounded by a rich habitat ecotone of the xeric shrublands—desert chaparral, montane chaparral and piñon-juniper woodlands, and conifer forest plant communities.

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TAs: Nick Anderson
Cover Photo: Nick Anderson

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1. Schedule

1.1 Field Trip Schedule - October 24-26, 2025

Day	Approximate Time	Activity	Address (put into google maps)	Talks	Duration	Bathroom	Drive Time
Day 1 - 10/24	7:30 AM	Meet at Arms Circle + make lunch	4VPF+F79 Pasadena, California		1:00	X	
	8:30 AM	Leave Arms Circle					1:20
	9:50 AM	First Mcdonalds Ever		Sarah, Simon	0:30	X	0:30
	10:50 AM	Mormon Road	6PM4+9F San Bernardino, California	Korbi, Issac			0:30
	11:20 AM	Silverwood lake lunch	7MP4+QW, Crestline, CA 92345	Forrest	0:30		1:10
	1:00 PM	Bowen Ranch/Setup Camp	9R7P+QF Apple Valley, California		1:00	X	
	2:00 PM	Hike to Deep Creek			0:40		
	2:40 PM	Hang at Creek		Elena, Yurina, Amanda	2:30		
	5:10 PM	Hike to Camp			1:00	X	
		Sunset is at 6:07 pm					
Day 2 - 10/25	7:00 AM	Breakfast + break camp + make lunch			1:30	X	
	8:30 AM	Drive to Dish Hill	34.60909, -115.94439				2:15
	10:45 AM	Hunt for Xenoliths + lunch		Sophia, Jordan	1:45		1:20
	1:50 PM	Mitchell Caverns Tour	WFVP+FJ Essex, California	Jordan	2:30	X	1:10
	4:30 PM	**We have a 2pm appt at Mitchell**					
		The group will split into 2 - 12 & 13 people					
		Half will go on cave tour. Other half will go in the am remaining half will go to:					
	1:50 PM	Kelso Dunes Surfing or	W769+8H Flynn, California	Abby, Hannah, Ben	2:30	X	
		Mojave Lava Tube	668X+GC Rainbow Wells, California				
	6:00 PM	Dinner at Providence Mountains SRA camp	WFXR+F9 Essex, California	Tina		X	
		Sunset is at 6:06 pm					
Day 3 - 10/26	7:00 AM	Breakfast + break camp + make lunch			1:30	X	
	8:30 AM	Talks and Free Time		Olivia, Ting-Juan	2:30		
	11:00 AM	Kelso Dunes Surfing/Lava Tube for first group + lunch		Abby, Hannah, Ben	2:30		
		We have a 11am appt at Mitchell for the second group					
		Stops below will change:					
	1:30 PM	Drive to Mud Hills Barstow through lake Manix					2:15
	3:45 PM	Rainbow Basin Barstow		Becky, Eran	0:30	X	1:20
	5:35 PM	Wrightwood Actinolite/Blackhawk Slide	34.35637, -117.61891		0:20		0:10
	6:05 PM	Fault Gouge Stop/Big Pines Visitor Center		Victor	0:15	X	1:20
	7:40 PM	Mt. Wilson Observartory	6WGV+63 Mt Wilson, California	Ruth, Simon, Natalia		X	0:45
	8:25 PM	Arms Circle				X	
		Sunset is at 6:05 pm					

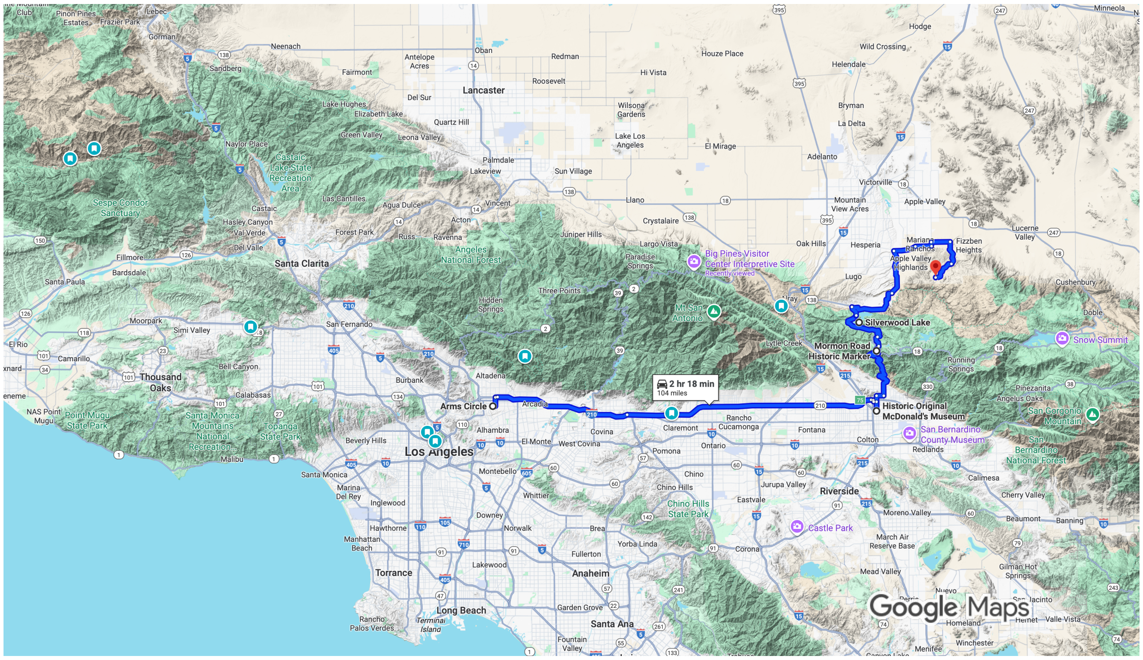
2. Routes

2.1 Day 1: Friday October 24, 2025

Google Maps

Arms Cir, Pasadena, CA 91125 to
Deep Creek Hot Springs Bowen Ranch, 5900 bowen ranch road,
Hot Springs Trl, Apple Valley, CA 92308

Drive 104 miles, 2 hr 18 min


Arms Circle
2 hr 18 min
104 miles
Silverwood Lake
Mormon Road Historic Marker
Historic Original McDonald's Museum
Apple Valley
Los Angeles
Pasadena
Lancaster
Palmdale
Santa Clarita
Victorville
Hesperia
Riverside
Anaheim
Long Beach
Santa Ana
Google Maps

Map data ©2025 Google 5 mi

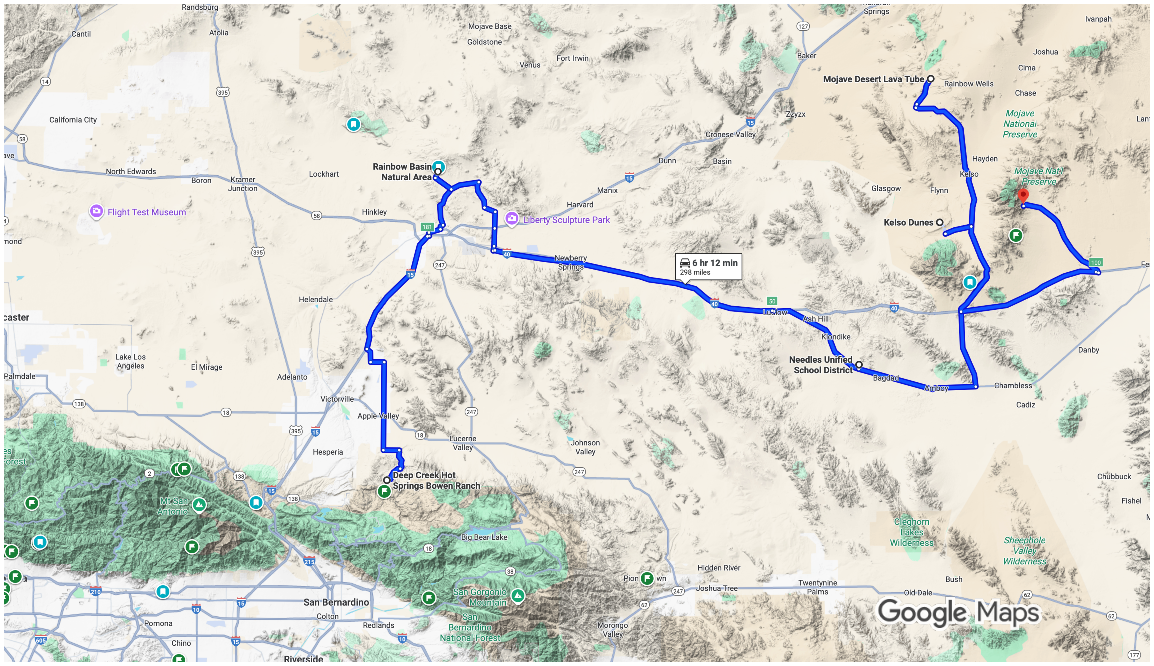
via I-210 E and CA-210 2 hr 18 min

Fastest route now due to traffic conditions 104 miles

2.2 Day 2: Saturday October 25, 2025

Deep Creek Hot Springs Bowen Ranch, 5900 bowen ranch road, Hot Springs Trl, Apple Valley, CA 92308 to Mitchell Caverns, 38200 Essex Rd, Essex, CA 92332

Drive 298 miles, 6 hr 12 min

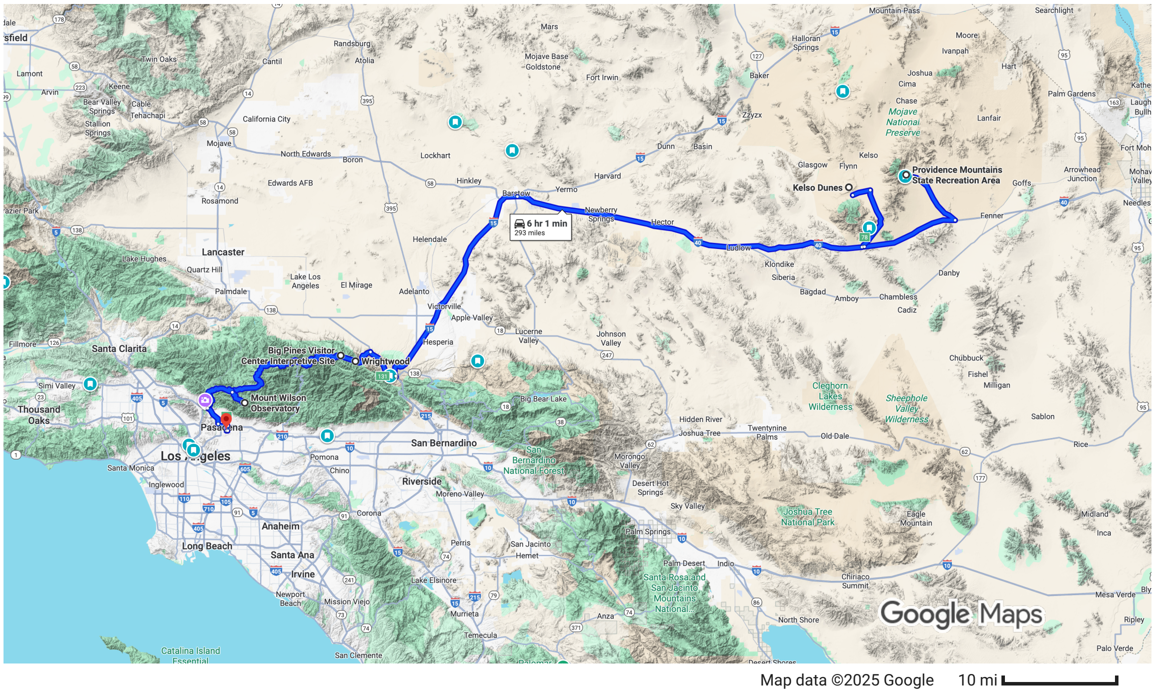

Mojave Desert Lava Tube
Rainbow Basin Natural Area
Liberty Sculpture Park
Flight Test Museum
6 hr 12 min
298 miles
Kelso Dunes
Needles Unified School District
Deep Creek Hot Springs Bowen Ranch
Mojave National Preserve
Barstow
Victorville
Apple Valley
Hesperia
Newberry Springs
Ludlow
Amboy
Kelso
San Bernardino
Riverside
Google Maps

Map data ©2025 Google 10 mi

via I-15 N 6 hr 12 min

Fastest route now due to traffic conditions 298 miles

2.3 Day 3: Sunday October 26, 2025


Kelso Dunes
Providence Mountains State Recreation Area
Big Pines Visitor Center Interpretive Site
Wrightwood
Mount Wilson Observatory
Pasadena
Los Angeles
Barstow
6 hr 1 min
293 miles
Google Maps
Map data ©2025 Google
10 mi

via Essex Rd, I-40 W and Kelbaker Rd

6 hr 1 min

293 miles

Fastest route now due to traffic conditions

⚠ This route has restricted usage or private roads.

3. Useful Information

3.1 Bowen Ranch Campground Rules and Information

Bowen Ranch Campground Information:

- **Location:** Deep Creek Hot Springs area, San Bernardino National Forest
- **Host Contact:** Jess Ebert / +1 (760) 261-1054
- **Check In:** Contact host for check-in time
- **Check Out:** Contact host for check-out time

Bowen Ranch Campground Regulations:

- **Water:** Potable drinking water is available at this listing (spigot, hose, pump or well, bottled water or jugs).
- **Fire Safety:** Campfires are allowed at this listing (firepit, private). Be fire safe—always check state and local fire regulations before having a campfire and know how to properly extinguish your fire.
- **Campfire Rules:** No gathering firewood on the property. Firewood for sale on site, $10 bundle. Firewood must be purchased on site or prepaid through Hipcamp. No gathering of wood or combustible material of any sort allowed on or off the property per BLM rules.
- **Fire Materials:** No fireworks or firearms permitted.
- **Restroom:** A toilet is available at this listing (flush toilet, pit toilet, composting toilet).
- **Pets:** Pets are allowed at this listing (off leash). Must be leashed on trail. Pets must be on a leash at all times on forestry land and are not allowed in the pools.
- **Shower:** A shower is available at this listing.
- **Waste Disposal:** Waste disposal is available at this listing (recycling bin, trash bin).
- **Kitchen:** Kitchen and cooking equipment are not available.
- **Quiet Hours:** Quiet time after midnight. Music and generators should not be heard from other campsites.
- **OHV/Vehicle Rules:** No OHV riding on the campground property, except to unload and ride to OHV trails accessible from Bowen Ranch Rd. 5mph and must stay on established roads, no off-road cross country travel anywhere.
- **Hot Springs Area:** The Deep Creek Hot Springs are located on US Forestry land and designated as day use only. No fires or glass near the springs. Pets must be on a leash at all times on forestry land and are not allowed in the pools.
- **Navigation Warning:** DO NOT use Google/Apple Maps for final approach. DO NOT take routes using Deep Creek Rd, Japatul, Bonita Vista, or Milpas. AVOID neighbor's property at 3-way split (1/2 mile before entrance)—if you see old cabin shack, turn around immediately. Look for official Bowen Ranch sign with telephone poles and metal water tank.
- **Directions from I-15:** Take Ranchero Rd exit in Hesperia, drive east 8 miles to Arrowhead Lake Rd. Turn left, drive 1 mile to Rock Springs Rd. Turn onto Rock Springs Rd, drive 3 miles past Deep Creek Rd. Continue onto Roundup Way 2–3 miles. Turn left on Central Rd (1/2 mile), right on Ocotillo Way (3 miles), right on Bowen Ranch Rd (dirt road, 6.2 miles to entrance). At mile 5.7, KEEP RIGHT at 3-way split.

3.2 Providence Mountains SRA Rules and Information

Providence Mountains SRA Campground Information:

- **Location:** Eastern Mojave Desert, 4,300 feet elevation, surrounded by Mojave National Preserve
- **Park Contact:** 760-928-2586
- **Check In:** 2:00 PM
- **Check Out:** 12:00 PM
- **Reservations:** Required via www.reservecalifornia.com or 1-800-444-7275
- **Cost:** Campsite $25/night, extra vehicle $10/night

Providence Mountains SRA Campground Regulations:

- **Water:** Water is scarce at the park. Bring your own water for drinking, washing, and cooking.
- **Fire Safety:** Contact park for current fire regulations. Desert conditions require extreme caution.
- **Campsite Limits:** Maximum 2 vehicles and 8 people per campsite. Five developed campsites available Friday and Saturday nights only.
- **Restroom:** Park facilities available (contact for details).
- **Pets:** Contact park for pet policy.
- **Shower:** Contact park for availability.
- **Waste Disposal:** There is no trash service at the park. Pack it in and pack it out.
- **Kitchen:** No food available at park or within 25 miles. Bring all meals and cooking equipment.
- **Quiet Hours:** 10:00 PM – 6:00 AM. Generators off 8:00 PM – 8:00 AM.
- **Gate Access:** Front gate closes at 5:00 PM. If arriving after 5:00 PM, call park for gate code.
- **Navigation Warning:** DO NOT RELY ON GOOGLE MAPS or other navigational apps—they often give dangerous 4WD routes. Park is ONLY accessible from Essex Road. Bring a map and know your route.
- **Directions from I-40:** Exit 100 (Essex Road), 56 miles west of Needles, 100 miles east of Barstow. Follow Essex Road 16 miles northwest from exit to park entrance.

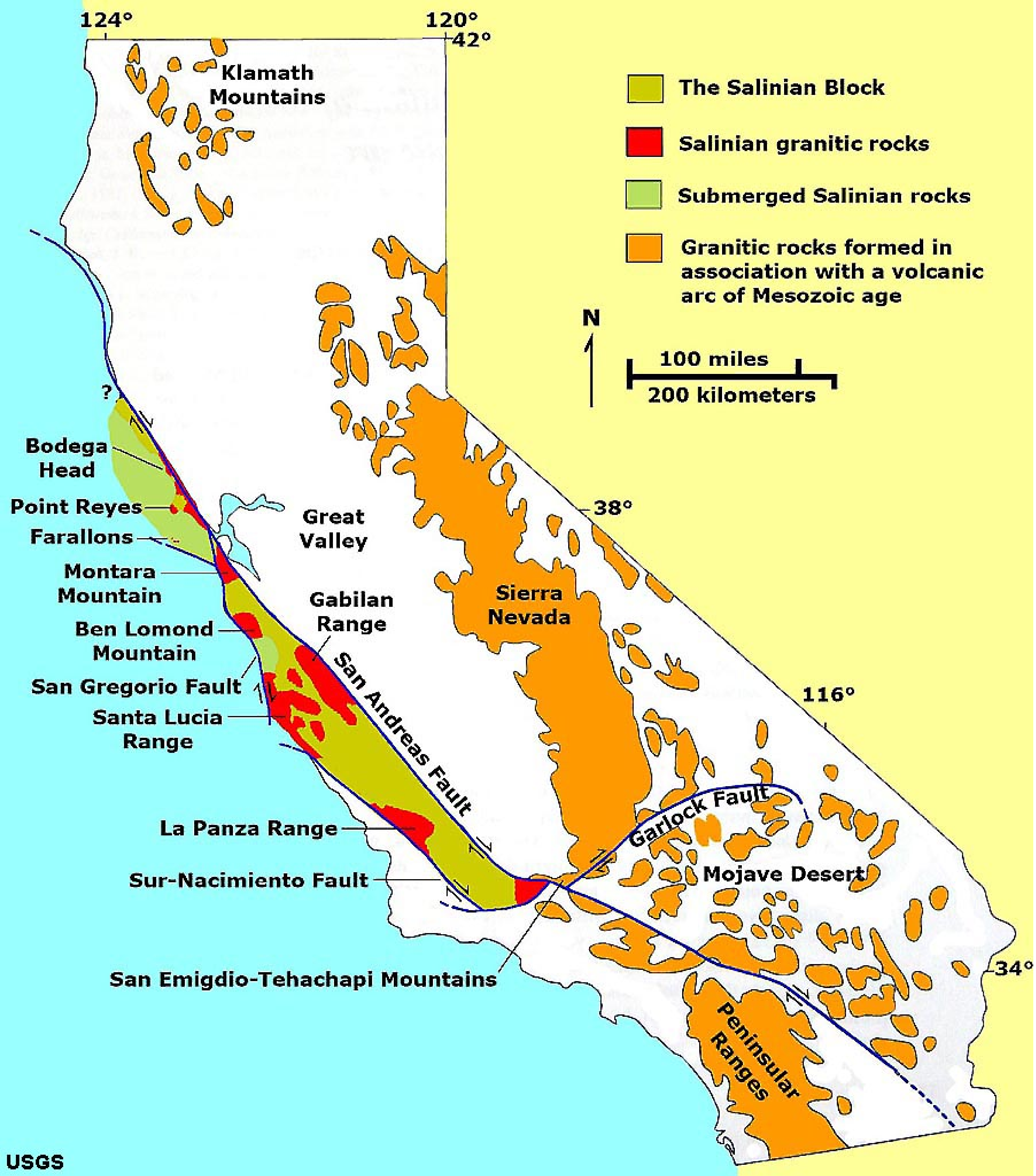
3.3 Mitchell Caverns Tour Rules and Information

Mitchell Caverns Tour Information:

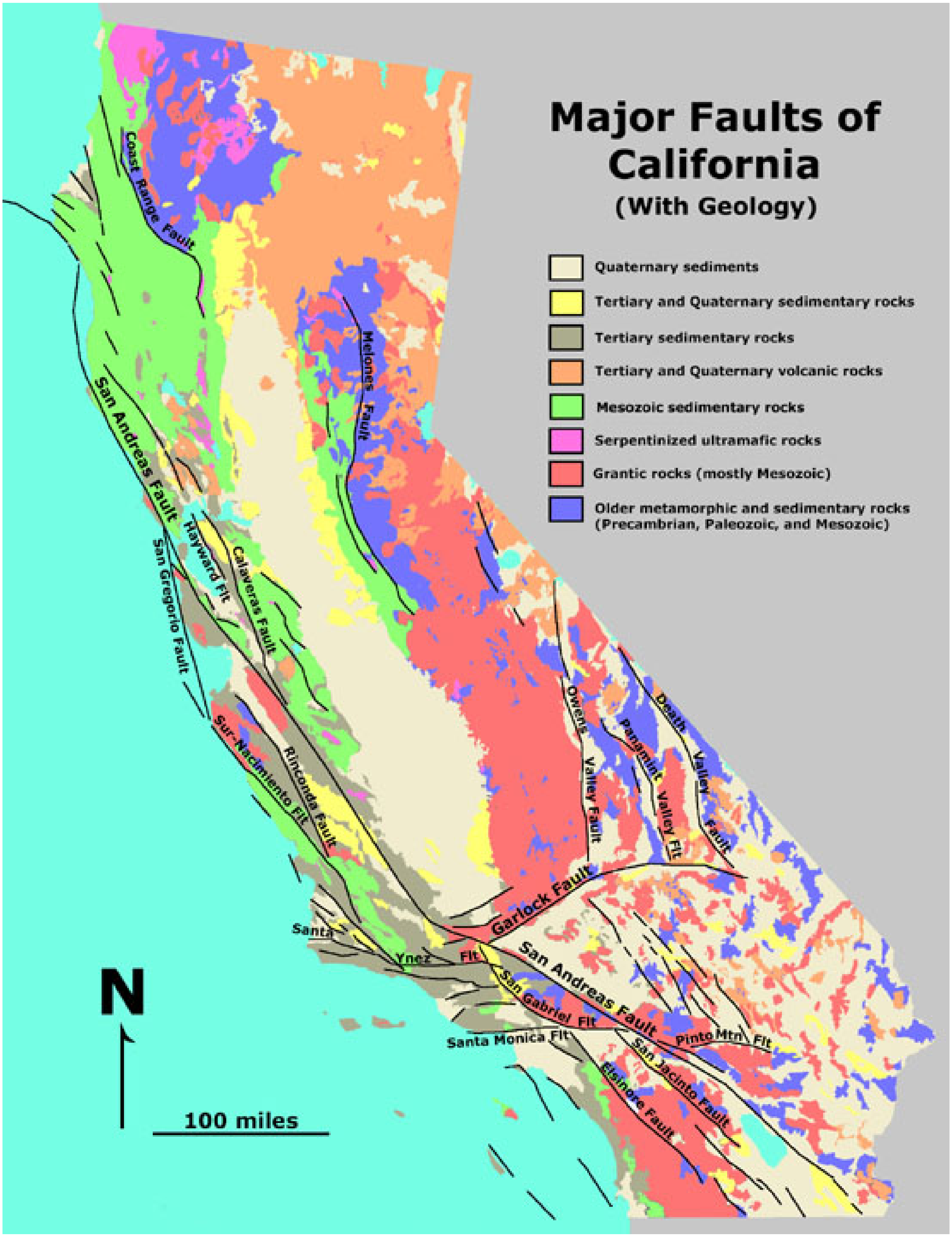
- **Reservations:** Required via reservecalifornia.com (search "Providence Mountains SRA") or call 1-800-444-7275.
- **Tour Details:** 1.5 mile vigorous roundtrip hike plus 2-hour guided cave tour. Arrive 30 minutes before scheduled tour.
- **Tour Times:** October–May: 11:00 AM and 2:00 PM (Fri–Sun plus holiday Mondays). June & September: 10:00 AM (Fri–Sun plus holiday Mondays). Closed July–August, Christmas, and New Year's Day.
- **Cost:** Adults $20, Children (16 and below) $10, Seniors $19.
- **Cave Features:** El Pakiva and Tecopa caves with stalagmites, stalactites, helictites, lily pads, draperies, curtains, rimstone dams, and cave coral. Temperature inside caves ranges in the 60s.
- **Physical Requirements:** Not ADA accessible. Areas as low as 62 inches and as narrow as 14 inches. Wear closed-toe shoes suitable for hiking.
- **White Nose Syndrome Protocol:** Do not bring clothing, shoes, or gear that have been in other caves, mines, or lava tubes in the last 10 years. If necessary, decontaminate with hydrogen peroxide wipes available at park.
- **Trail Access:** Cave Trail, Mary Beal Nature Trail (0.5 mile), and Niña Mora Trail (0.5 mile) available for day use.
- **Wildlife:** Bighorn sheep, mountain lions, coyotes, bobcats, rattlesnakes present. View from safe distance, never feed or approach.
- **Essential Supplies:** Bring extra water, food, sunscreen, layers of clothing, first aid kit, and full gas tank (nearest fuel 24 miles away in Fenner).

4. Maps

4.1 (1) Simplified Distribution of Granitic Basement in California


124°
120°
42°
Klamath Mountains
The Salinian Block
Salinian granitic rocks
Submerged Salinian rocks
Granitic rocks formed in association with a volcanic arc of Mesozoic age
N
100 miles
200 kilometers
?
Bodega Head
Point Reyes
Farallons
Montara Mountain
Ben Lomond Mountain
San Gregorio Fault
Santa Lucia Range
Great Valley
Gabilan Range
Sierra Nevada
38°
San Andreas Fault
116°
Garlock Fault
Mojave Desert
La Panza Range
Sur-Nacimiento Fault
San Emigdio-Tehachapi Mountains
34°
Peninsular Ranges
USGS

4.2 (2) Simplified Geologic Map of Faulting in California

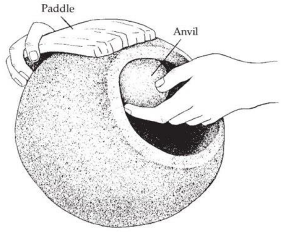

Major Faults of California
(With Geology)
Quaternary sediments
Tertiary and Quaternary sedimentary rocks
Tertiary sedimentary rocks
Tertiary and Quaternary volcanic rocks
Mesozoic sedimentary rocks
Serpentinized ultramafic rocks
Grantic rocks (mostly Mesozoic)
Older metamorphic and sedimentary rocks (Precambrian, Paleozoic, and Mesozoic)
Coast Range Fault
Melones Fault
San Andreas Fault
Hayward Flt
San Gregorio Fault
Calaveras Fault
Sur-Nacimiento Flt
Rinconda Fault
Owens Valley Fault
Panamint Valley Flt
Death Valley Fault
Garlock Fault
Santa Ynez Flt
San Andreas Fault
San Gabriel Flt
Santa Monica Flt
Pinto Mtn Flt
San Jacinto Fault
Elsinore Fault
N
100 miles

5. Talks

5.1 (1) California Indians

(1) Seed beater from Santa Rosa (NMAI)

(2) Rabbit stick from Arizona (Penn Museum)



(3) Paddle-and-anvil pottery technique

Pyrobiodiversity: The Tongva and Serrano/Yuhaaviatam

Isaac N. Aguilar

The early settlement of California initiated in times of considerable environmental change during the late Pleistocene and early Holocene (10-25 kya). Over the last 13 kya (or more), multiple distinctive groups with their own languages and cultural practices have migrated to California (Heizer and Elasser 1980). Long-term interactions with an ever-changing natural world have produced a diversity of languages, cultures, and polities that perpetuate in dynamic evolution. The intersection of three key variables (**elevation**, **distance** from the ocean, and **latitude**) develops a myriad of microclimates and California's iconic biodiversity that produces a backdrop of resource heterogeneity for the **pyrodiversity economies** of California Indians. The main reason why California Indians modified the landscape through fire and other cultivation methods was to enhance the growth of economically valuable plants and animals in local regions. Manufacturing perishable objects like baskets, hunting nets, and ceremonial regalia required **immense** and **constant harvest**. Fires encourage young, straight sprouts to grow; a medium-sized cooking basket requires approximately 3,750 deergrass stalks from 75 plants (Blackburn and Anderson 1993).

Pyrodiversity refers to the **landscape heterogeneity** and **diverse biota** that result from various stages of **plant succession** as those plants **recolonize burned areas** (Martin and Sapsis 1992). When staple foods like acorns and large game are scarce, the creation of patchy mosaics comprising diverse kinds of plants and animals provided optimal settings for harvesting foods, medicines, and raw materials – especially during times of environmental perturbations. Prescribed burning produces edges or transitions between different habitat types and previously burned parcels that enhances local biodiversity (Lewis 1993). Vegetation in different ecological communities might have been burned at different intervals to augment a patchwork of distinctive habitats with different **succession rates** of plants and animals. Most intensive management likely occurred near major settlements, although logistical travel across a territory occurred frequently for harvesting outlying patches, processing in bulk, and transporting back home (Vale 2002). The **fire-return interval** of a specific habitat depends on factors like the intended mix of economic resources, fuel sources, climatic conditions, and timing and number of natural ignition sources, and the spatial pattern of previous fires. Reconstructing past fire regimes is challenged by significant spatiotemporal variation related to environmental variables like temperature, precipitation, elevation, aspect, distance from the ocean, vegetation types, and others. **Anthropogenic fire regimes** in the late Holocene characterized mid- to low-elevations with small, frequent, low-severity fire (Stuart and Stephens 2006). The Southern Deserts province is the only major exception, where low fuel loads and discontinuous distribution of fuels at low elevations can hinder fire spread, resulting in patchy spatial patterns of burns with long return intervals (Stephens et al. 2007). The full impact of anthropogenic fires is not yet known, although the great majority of plant species used by Native Californians are **fire stimulated** (Brooks and Minnich 2006). The advent of **fire suppression** practices after 1905 changed fire regimes dramatically across California, with fewer, larger, and more severe fires. Fire suppression has greatly altered the **composition** and **structure** of local habitats, often producing increases in stand density, the accumulation of floor debris, a decrease in the native plant biodiversity, and the spread of fire inhibited species (Sugihara and Barbour 2006).

California Indians of the Southern Deserts employed various **cultivation methods** in the management of the regional landscape, but they were not farmers. They reserved the most labor-intensive methods per unit area to tend **nonfood resources** such as growing tobacco and plants for basketry and cordage materials. **Seed sowing** was limited primarily to the Southern Deserts province and places adjacent to the Great Basin. Ethnographic reports of sowing describe the tending of wild tobacco (*Nicotiana sp.*) patches involving burning areas, sowing seeds, and pruning individual plants (Anderson 2005). Indian groups in the Southern Deserts practiced "protopyrobiodiversity" designed for the arid Colorado Desert and Mojave Desert with seed sowing and the **addition of domesticates** like corn into the greater mix of plant foods available to them (Wallace 1980 and Shackley 2004).

Two major language families are represented in the Southern Deserts: the **Takic**-speaking (Uto-Aztecan stock/family) Serrano, Kitanemuk, Luiseno, Cupeno, and Ahuilla; and the **Yuman**-speaking (Hokan stock) Kumeyaay, Paipai, and Kilwa. Each localized lineage (70-120 individuals) owned certain highly productive areas of agave (*Agave* spp.), mesquite, or acorns, but the intervening land could be used by anyone for either hunting or gathering. Movement to seasonal villages or camps that were near pinyon (*Pinus* spp.) and marine resources occurred during various times of the year (Bean 1972, Hicks 1963, and Meigs 1939).

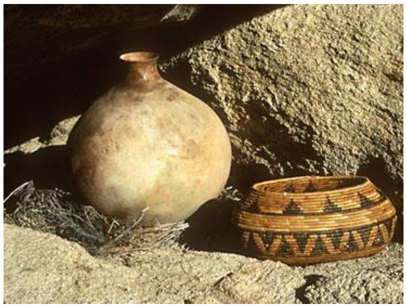
The Indigenous groups of the region harvested a variety of plant, animal, and mineral resources for their subsistence and cultural practices. A **seed beater** (1) was used to collect seeds from **saltbushes** (A) then they were hulled in a wooden mortar, winnowed, and soaked, then placed in a pit lined with hot rocks. After baking for several hours, the seeds were removed from the pit, parched, and ground. The meal was mixed with water before eating or as a topical liniment to treat bone and muscle pain (Owen 1962). The **toloache** (B) was used for its hallucinogenic properties, though its ingestion proves fatal without proper preparation. In the initiation of boys into manhood, puberty rites included specially grinding dried toloache root into a liquor. The use of the north pointing part of the toloache root allowed shamans to transcend reality or chewing the root enhanced luck and perception (Hohenthal 2001). The pulpy fruits of the **prickly-pear cactus** (C) remain an important food source and can be eaten fresh in the summer or ground into a fine meal for storing and making cakes. Traditionally, the spines were used as tattoo needles and the pads could be dried and used for splints or soothing festering wounds (Owen 1962). **Hares and rabbits** (D) made up the most abundant and most easily obtainable source of meat. Desert cottontail (*Sylvilagus audobonii*) and the Black-tailed Jackrabbit (*Lepus californicus*) were the primary game animals caught in communal drives, including the use of nets, brush fences, and/or intentionally set fires. A type of non-returning boomerang called a **rabbit stick** (2) or bow and arrows were used to dispatch animals before roasting in coals, over a fire, or in an earth oven to grind into pemmican for later use. Blankets and clothing can also be made from their skins. Clay for **ceramics** and stems for **baskets** (E) are carefully selected and processed. Pottery is made using the **paddle-and-anvil technique** (3) and used for cooking or food and water storage. Certain clays are also used in face painting.

(A) *Atriplex* spp. (Saltbush)

(B) *Datura* spp. (Toloache)

(C) *Opuntia* spp. (Prickly-pears)

(D) Leporidae (Hares and Rabbits)


(E) Clay pot and woven basket

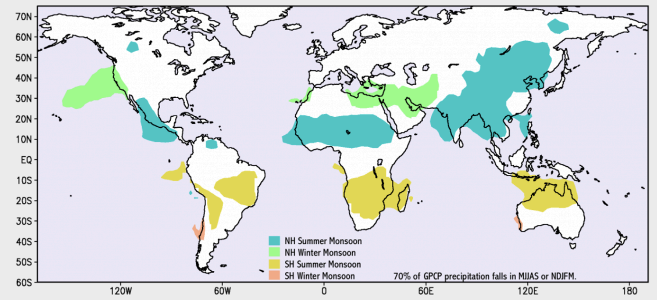
5.2 (2) Monsoon Systems

The Southwest American Monsoon

Olivia Alcabes

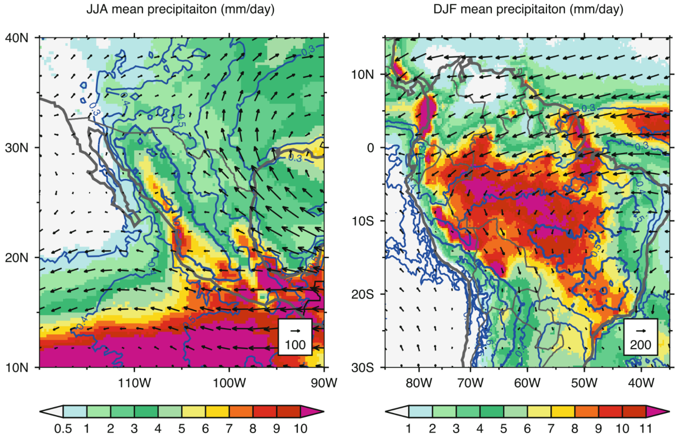
What is a Monsoon?

The definition of a monsoon is actually somewhat ambiguous, as the scientific community has changed the definition over time. Colloquially, the term “monsoon” is often used to refer specifically to the “rainy” season caused by this seasonal change in climatological patterns, although sometimes it can be used to describe dry conditions caused by the same change. Historically, the scientific term “monsoon” has meant a change in the prevailing winds and precipitation pattern of a region, but more recent studies have noted that these monsoons are not always clearly affiliated with wind circulation changes. Now, a more accurate description may focus purely on a seasonal pattern of precipitation differences, with regions experiencing a “wet” season and a “dry” season (Farnsworth 2025). Although in the past monsoons have often been discussed as purely summer phenomena, there are also significant winter monsoons throughout the world (Fig. 1, Farnsworth 2025).

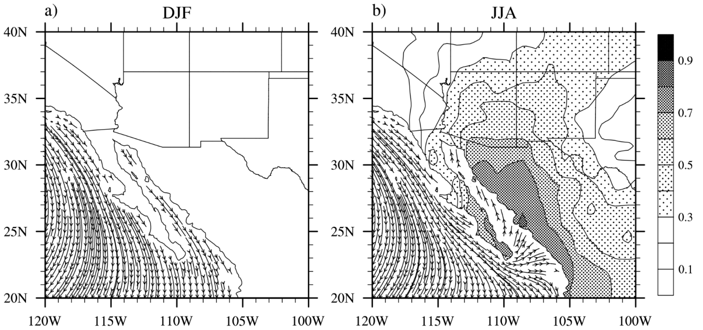


70N
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
120W
60W
0
60E
120E
180
NH Summer Monsoon
NH Winter Monsoon
SH Summer Monsoon
SH Winter Monsoon
70% of GPCP precipitation falls in MJJAS or NDJFM.

Figure 1: Regions where at least 70% of annual precipitation occurs in the 5-month seasons indicated.This is only one of many possible definitions of monsoon regimes around the globe. Data are from GPCP version 2.5 For 1979-2008 provided by P. Dirmeyer.



JJA mean precipitaiton (mm/day)
DJF mean precipitaiton (mm/day)
40N
30N
20N
10N
110W
100W
90W
100
0.5
1
2
3
4
5
6
7
8
9
10
10N
0
10S
20S
30S
80W
70W
60W
50W
40W
200
1
2
3
4
5
6
7
8
9
10
11



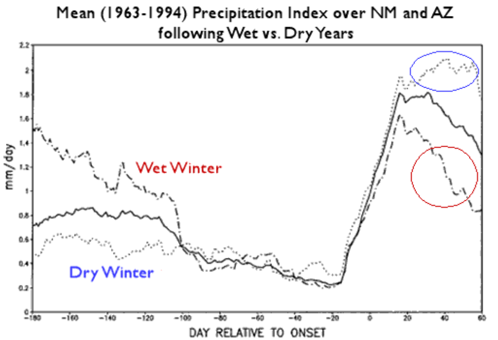
a)
DJF
b)
JJA
40N
35N
30N
25N
20N
120W
115W
110W
105W
100W
0.9
0.7
0.5
0.3
0.1

What makes the North American Monsoon (NAM) and South American Monsoon (SAM) different from other monsoons?

Most monsoons around the globe are significantly impacted by regional topography, complicating how to compare them to each other. As compared to the Asian monsoon, the North and South American monsoons do not experience nearly as significant of a wind reversal. For the North American monsoon, the circulation change is shallower, as the wind directions change over the near-surface and form low-level jets but don’t tend to change the prevailing wind direction aloft (Bordoni et. al. (2004), Pascale et. al. (2020)). The South American monsoon does not have a significant change in seasonal wind patterns, although does experience significant changes in precipitation, complicating the definition of monsoon as discussed previously (Farnsworth 2025). The topmost two figures to the left are taken from Pascale et. al. (2020) and show the climatological mean precipitation and vertically averaged moisture fluxes during monsoon season for both the NAM and the SAM, with blue contours showing the ratio of mean precipitation during the monsoon season to annual mean precipitation.

Features and Drivers

The bottom two figures to the left come from Bordoni et. al. (2004) and show the mean streamlines of the 10 meter winds over the Gulf of California as derived from high resolution QuikSCAT observations in the Northern Hemisphere winter (a) and summer (b). The NAM originates over the Gulf of California in mid-June, and reaches the Southwest US by mid-July. It normally lasts through about mid-September, and is especially noticeable in Arizona and New Mexico. These regions experience strong convection and thunderstorms on summer afternoons (Bordoni et. al. (2004), Pascale et. al. (2020)). Occasionally, the moisture can make its way all the way over to Southern California, and can result in more moist conditions than typically occur in the Mojave desert, although actual convection and thunderstorms in Southern California remain very rare in the summer. Overall, monsoons are closely dynamically linked to the large-scale circulation of the atmosphere. Specifically, fluctuations in the Hadley Cell and the Inter-tropical Convergence Zone (ITCZ) seem to have strong influences on monsoons, although how exactly these dynamics are linked remains an active field of study (Bordoni & Schneider (2008), also talk to Ryan Eusebi about this!). Remote sea surface temperatures (SSTs) also are correlated with the strength of the monsoon in a given year (Pascale et. al. (2020)). Additionally, the conditions of the preceding winter can affect the strength of precipitation deposited by the monsoon in the summer, with wet winters followed by drier monsoons and dry winters followed by wetter monsoons (Higgens et. al. (1998)). The topography of Baja California and Mexico likely have a significant influence on the NAM dynamics, as models that don't fully resolve the region fail to reproduce the low-level jet seen by observations during the monsoon period, and can also have biases in the SSTs in the Gulf of California.

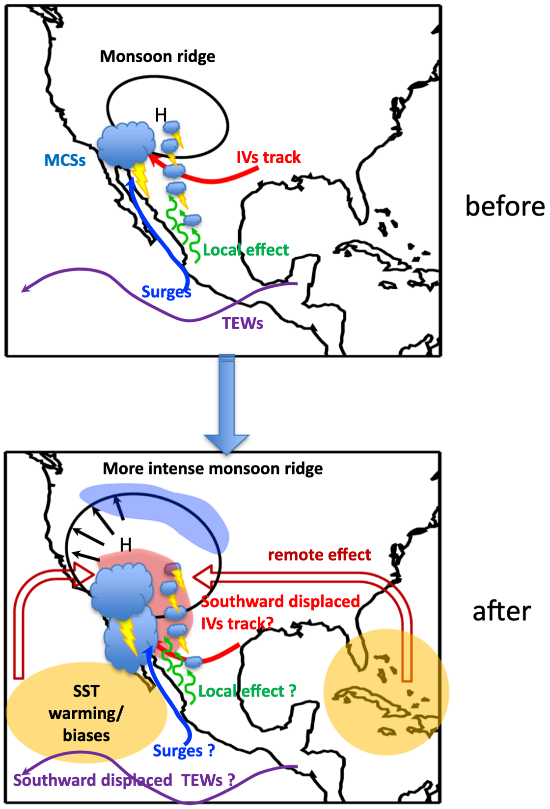


Higgins et al (1998) J. Climate

The Future of the North American Monsoon

Predicting how all monsoons will change under anthropogenic climate change, especially in regards to changes in precipitation, is extremely important when it comes to planning for future flood mitigation and agricultural practices. The NAM is no exception, as the regions in the Southwest US that experience the monsoon are often extremely dry and the monsoon has strong contributions to annual rainfall yields. However, Pascale et. al. (2020) show that both global and regional models diverge significantly when it comes to predicting the future of the American Southwest, with some indicating increases in precipitation, and others indicating decreases. Even when models are in agreement with how things might change in the future, they are often unable to accurately capture monsoon dynamics in present day conditions, making it hard to ascertain how well we can trust their results. The lack of understanding suggests that there is work to be done on the process side of monsoon dynamics: namely, we need to understand the first order processes that monsoon dynamics are sensitive to, and then try to constrain how those processes might change under a warming climate.

We can try to make some predictions based on what we do know. For example, Zhou et. al. (2011) looked at global precipitation data and showed a "wet gets wetter" and "dry gets drier" trend in the tropics. Therefore, it is possible that monsoon regions that already get a lot of precipitation, specifically higher elevation regions for example, may be more likely to get more precipitation in the future. The extent to which this paradigm actually applies to monsoons would be interesting to investigate further. Finally, Pascale et. al. (2020) came up with a schematic (to the right) showing the various processes that impact the North American Monsoon and how they may change in the future. For example, they show that warmer SSTs would suppress convection over land, weakening the monsoon. However, by the same reasoning, accelerated evaporation over land reservoirs in the Southwest could accelerate convection locally there. Land use by humans will likely have a large impact on the extent to which the latter matters. While we may be able to speak to the direction each individual process may go, the real question for monsoon prediction is the tradeoffs between processes, and constraining which ones will have the dominant effect.



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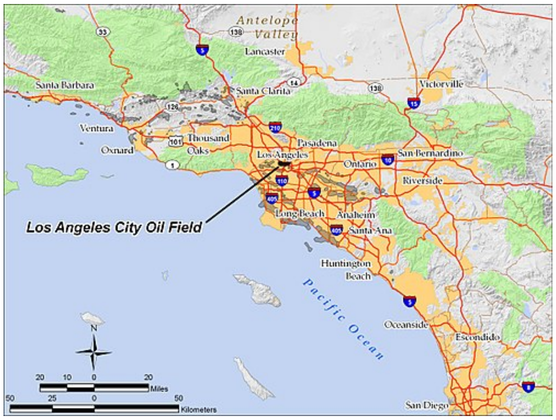
5.3 (3) LA Oil Field

Los Angeles Oil Fields

Simon Andren - GE136a



Introduction

The Los Angeles region is richer in oil per area than Saudi Arabia. Extracting and refining oil have been of both cultural and economic significance to the region. It started with the Los Angeles City Oil Field, a roughly 1,000-acre field in the heart of downtown and then expanded southward to Huntington Beach, Long Beach, Santa Fe Springs, and offshore along the coast. Together, these fields made Los Angeles and Southern California the largest producers of crude oil in the U.S. during the early twentieth century. Oil shaped the city's development. Entire neighborhoods were built on top of oil fields, and the wealth from petroleum funded much of LA's early industrial growth. Even today, a few active wells exist.

The geochemistry of oil

Crude oil starts with the preservation of organic matter in reducing environments. After sedimentation, the first step is diagenesis, where biopolymers begin to degrade, small molecules condense into larger ones, and reactions like dehydration (loss of H_2O) and decarboxylation (loss of CO_2) occur. This happens relatively close to the surface, typically below 100 °C, and often still involves biological activity. As burial continues, temperatures increase, and catagenesis, an abiotic breakdown of the hydrocarbons, starts. Here, chemical bonds begin to break, making long carbon skeletons into smaller hydrocarbons. The degree of this breakdown is often referred to as thermal maturity, a measure of how "cooked" the organic material has become. More mature systems tend to yield lighter hydrocarbons (shorter chains), while less mature ones contain heavier fractions.

Broadly, two main types of environments produce fossil fuels. Terrestrial sources, which come mainly from plant carbohydrates, have a high O/C ratio and generally form coals. Because of their higher oxygen content, these sources are more oxidized, yield less energy and can thus be considered less "green". Marine sources, on the other hand, are dominated by lipids (High H/C ratio) derived from algae and plankton. These are more reduced and form crude oil. The Los Angeles Basin, with its marine Miocene source rocks, is a case of this.

Geology of LA oil fields

The Monterey Formation, deposited between 18 and 6 million years ago (Early to Late Miocene), is the main source rock for most of California's oil. It stretches along the coast from south of Los Angeles up toward the San Francisco region. The formation is composed largely of highly siliceous shales. The slow deposition of shale, along with nutrient-rich, low-oxygen waters, led to conditions of high organic productivity and good preservation of organic matter, creating today's oils.

In the Los Angeles Basin, the Monterey was later folded and faulted during tectonic compression, creating traps where oil would accumulate. One example of this is anticlines, where hydrocarbons would move up through the source rock before encountering impermeable layers and accumulate at the top of the anticline. An example of this is Sulfur Mountain up towards Santa Barbara, where oil is flowing out into a little creek. As the name suggests, this oil is very sulfur rich leading to a very distinctive smell of rotten egg in the area.

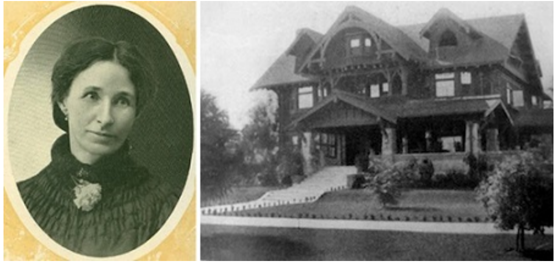
Picture of LA's many oil wells

History of LA oil fields

The oil fields in Los Angeles have long been used by Indigenous people. The local Tongva and Chumash people collected natural tar from the seeps around what is now the La Brea area and used it to build plank boats called Tomol. These boats were made by tying planks of wood together with rope and sealing the seams with tar. The Tomol was the most complex watercraft in North America at the time and allowed people to travel across the Santa Barbara Channel for trade and fishing.

The first oil extracted in Los Angeles came from the LA City Oil Field, discovered in 1892 by Edward L. Doheny. By the late 1890s, hundreds of wells had popped up, and there was a real oil rush in Los Angeles. At its hay-days, California produced almost a quarter of the world's oil.

One of the more interesting persons from that period was Emma Summers, also known as the Oil Queen of California. She started as a piano teacher and used $700 she had saved from teaching lessons to buy into a single well on the LA City Field. When it struck oil, she reinvested the profit and together with her salary as a piano teacher, she started buying up neighboring lots and wells. Over a few years, she went from musician to one of the most powerful oil operators in Los Angeles. By 1900, she controlled nearly half of the wells on the field, selling oil to local companies and hotels while still teaching piano at night.



Left: Emma Summers. Right: Her Mansion at Wilshire Boulevard

Santa Barbara Oil Spill

The significance of the oil extraction in Southern California is not only economic and cultural but also environmental. One of the most significant events in this history was the 1969 Santa Barbara oil spill, which became a turning point in public awareness of industrial pollution. In January 1969, a blowout occurred at Union Oil's Platform A in the Dos Cuadras Offshore Field, about six miles off the coast of Santa Barbara. The pressure release cracked the seafloor, and over the following weeks, an estimated three million gallons of crude oil spilled into the Pacific Ocean. Thick slicks washed ashore, covering beaches, harbor rocks, and the local wildlife. Thousands of seabirds, seals, and dolphins died. The event was widely covered by national media, prompting outrage across the United States and leading directly to the creation of the Environmental Protection Agency (EPA) and the first Earth Day in 1970.

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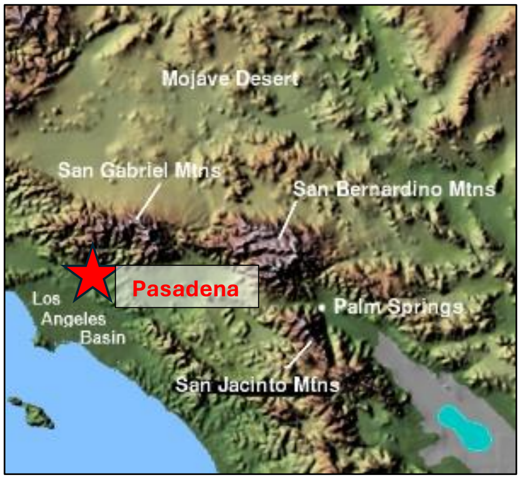
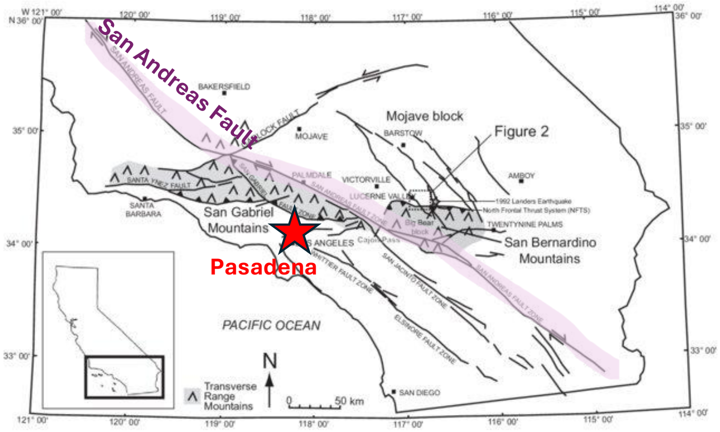
5.4 (4) San Bernardino Mountains

Geology of the San Bernardino Mountains & uplift history of the Transverse Ranges

Amanda L. Bednarick

The San Bernardino Mountains are composed of very old rock, but their current morphology was shaped by quite recent geologic forces. Just like Pasadena's backdrop the San Gabriel Mountains, the San Bernardino Mountains are part of the Transverse Ranges. Cajon Pass marks the divide between the San Gabriels and the more eastern San Bernardinos.


Mojave Desert
San Gabriel Mtns
San Bernardino Mtns
Pasadena
Los Angeles Basin
Palm Springs
San Jacinto Mtns


San Andreas Fault
SAN ANDREAS FAULT
BAKERSFIELD
MOJAVE
Mojave block
BARSTOW
Figure 2
AMBOY
SANTA YNEZ FAULT
SANTA BARBARA
PALMDALE
VICTORVILLE
LUCERNE VALLEY
SAN GABRIEL FAULT ZONE
SAN ANDREAS FAULT ZONE
1992 Landers Earthquake
North Frontal Thrust System (NFTS)
Big Bear block
TWENTYNINE PALMS
San Gabriel Mountains
LOS ANGELES
Cajon Pass
San Bernardino Mountains
Pasadena
WHITTIER FAULT ZONE
SAN JACINTO FAULT ZONE
ELSINORE FAULT ZONE
PACIFIC OCEAN
N
0
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Transverse Range Mountains
SAN DIEGO
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N 36° 00'
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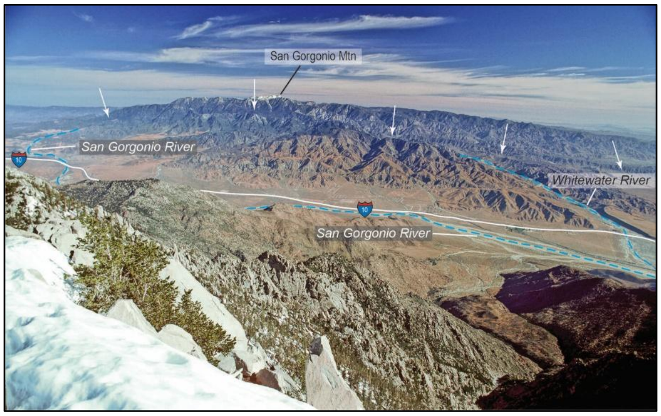
35° 00'
34° 00'
33° 00'
121° 00'

Mountain building

The San Bernardinos feature high-relief slopes and the tallest mountain in Southern California (Mt. San Gorgonio – 11,500 feet) because of intense uplift throughout the Cenozoic. The range is bounded by several major faults, including the San Andreas. The current tectonic regime, resultingly, is a thrust system, and transpressional forces and high-angle faulting cause an uplift rate of ~2 millimeters/year.

Thermochronometry and stream profile studies have identified a few periods of uplift in the San Bernardino Mountains. According to a 1989 paper, some proto-San Bernardino Mountains formed between 9 and 4 Ma to accommodate major movement along the thrust system. Then, beginning at ~2 Ma, activity along the San Andreas Fault uplifted the San Bernardino Mountains to what is more or less their present height and position.



Rocks

The first geologic map of the San Bernardino Mountains was published in1922. One hundred years later, many geologists have explored, mapped, and mined in the area. The aforementioned uplift and deformation resulting from the local tectonics has exposed rock units spanning over 1.5 billion years of Earth history in these mountains.

The mountains are divided into three areas, separated by faults. The main mass of the San Bernardinos are similar to Mojave Desert Province rocks (Proterozoic+ felsic rocks). West of the Mission Creek strand of the San Andreas Fault, rocks are not native to the San Bernardinos. Instead, they originated somewhere near the Coachella Valley (140 km farther southeast) and were displaced by tectonic activity. In the southeastern portion of the mountains, rocks resemble those of the San Gabriels. Notable rock units include granite and gneiss as old as 1.7 billion years, metasediments of the Neoproterozoic and Paleozoic when the desert southwest hosted a deep marine environment, and Cretaceous plutons related to subduction along the North American west coast. And of course, because of the steep slopes and fluvial activity today, there is a lot of Quaternary sediment cover and alluvium.

A discovery of gold in Holcomb Valley in 1855 set off Southern California's largest gold rush. Gold deposits are hosted in metamorphic skarns in the San Bernardinos.

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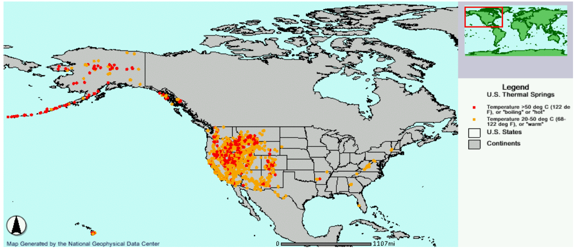
5.5 (5) Hot Springs Geology

Formation of Hot Springs and the Deep Creek Hot Springs

GE 136A | Elena Dworak | October 17, 2025

Hot springs are an important geothermal feature of Earth’s surface, and are a location where geothermally heated groundwater naturally flows onto the surface. This groundwater is heated by shallow reservoirs of molten rock in areas of high volcanic activity. In other non-volcanically active regions with fault lines, the fault has shattered rock that allows water to flow deeper through the Earth’s mantle where the temperature of rock is increased. These processes within the crust will allow the geothermally heated water to rise to the surface as a hot spring [Macdonald et. al, 1983].

Hot springs are commonly split into two types based on their water temperature (see Fig. 1), with “warm” hot springs having temperatures equal to and greater than 25 °C to below the local boiling point, and “hot” hot springs with temperatures equal to and greater than the local boiling point [Zhou et. al, 2023]. Most hot springs in California are “warm” as they are more often associated with fault lines, while hot springs in Alaska are mostly “hot” as they are associated with volcanic activity.


Legend
U.S. Thermal Springs
Temperature >50 deg C (122 deg F), or "boiling" or "hot"
Temperature 20-50 deg C (68-122 deg F), or "warm"
U.S. States
Continents
Map Generated by the National Geophysical Data Center
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Hot springs also have large amounts of dissolved minerals, as hot water is able to dissolve and absorb more minerals from rock than cold water. Common types of mineral variations include acid surface springs which are very acidic, alkaline chloride springs with silica, bicarbonate springs with carbon dioxide, and springs with dissolved iron. These minerals help support life of microorganisms and can produce abundant surrounding ecosystems [Des Marais & Walter, 2019].

Hot springs occur because of special geological and tectonic factors, and geothermal and hydrogeological conditions [Zhou et. al, 2023]. Hot springs have very different traits due to groundwater depth, type of heat source, material of the geothermal reservoir, and size of tectonic formations. Hot springs generally form by the process of groundwater entering through the Earth’s surface, the groundwater circulating deep within the surface and gaining heat from deep rocks and chemical properties through rock-water interactions,and the geothermal waters rising and emerging on the land surface as hot springs [Huang, 1993; Zhou et. al, 2023] .

Geological features can create preferential or blocked barriers for flow, this includes faults which are displaced areas of rock, these regions form contact springs and fissure/fault springs. A contact spring (Fig. 1, a) is where the water table outcrops along a fault, and fissure/fault springs (Fig. 1, b) are where a fault allows water to flow from a closed aquifer. Other subsurface geology creates three other types of springs, namely depression springs, tubular or fracture springs and volcanic springs. Depression springs (Fig. 1, c) are where the water table reaches the surface, and tubular or fracture springs (Fig. 1, d) are where water flows through karst conduits then is exposed to the surface at lower elevation. Volcanic hot springs. Volcanic hot springs have different characteristics than these four listed and are associated with volcanic activity and steam [Keegan-Treeloar et. al, 2022; Meinzer, 2023].

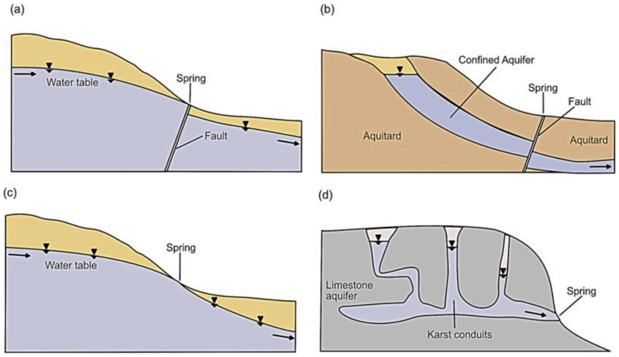

Figure 2: Image from [Keegan-Treeloar et. al, 2022; Meinzer, 2023], of models displaying varying hot spring formation types.

More locally in the northern Mojave Desert section of the San Bernardino National Forest, there are the Deep Creek Hot Springs. The Deep Creek Hot Springs have two locations half a mile apart from each other and are the main geologic features of the Deep Creek Canyon. The Deep Creek supports more diversity of wildlife habitats than any other region of the San Bernardino National Forest, and is considered a California Wild Trout Stream. There is an array of vegetation, with transiticonifer forest, sparse creosote, chamise and California buckwheat, oak and pinyon woodland, scattered mixed conifer, and healthy riparian habitats. The Deep Creek watershed has steeply sloping canyon walls that broaden in places, pictured to the right [Wild & River, 2024]. The Deep Creek area provides water for populations in the Mojave Desert which have limited access to water sources. Also, a parasitic amoeba was found in the Deep Creek Hot Springs in the late 1970's, showing how this region truly has a unique chemical and microbial environment [Wild & River, 2024].

Deep Creek lies within the upper San Gorgonio Mountains and the San Bernardino Mountains. The San Gorgonio Mountains contain mostly Mesozoic granite rocks and Precambrian igneous and metamorphic rocks while the San Bernardino mountains are mostly Mesozoic granite, both regions also have some Paleozoic marine sedimentary rocks. Deep Creek is in the Transverse Ranges of Southern California, which was formed by the San Andreas Fault tectonic forces between the North American and Pacific Plates . Deep Creek Canyon, among other river gorges, was caused by erosion through the steep San Bernardino Mountains [Wild & River, 2024]. The Deep Creek hot springs are to the east of the San Jacinto Fault line and San Andreas Fault line, in an tectonically active area. These springs are formed due to fault lines, and are categorized as fissure hot springs with carbonated rocks and limestone rocks [Schwarzenegger, 2010].

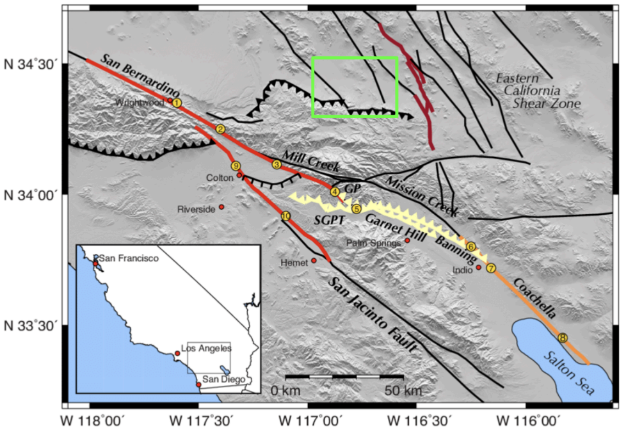

Figure 4: Green box is Deep Creek Hot Springs region, added onto a figure by [Hatch et. al, 2020]. Map of the San Gorgonio Pass region. "Fault traces of the San Andreas fault are labeled (SGPT-San Gorgonio Pass thrust). Rupture traces considered in this study are highlighted: A.D. 1992 Landers earthquake (dark red)".

The Deep Creek Hot Springs are within the Eastern California Shear Zone, approximately within the green rectangle marked. This is a highly tectonically active area, so the hot springs receive geothermally heated water through circulation within deeper rocks, which then emerge to the surface.

Overall, there are many regions of tectonic activity within California mountain ranges leading to hot spring formations. These hot springs and their corresponding watersheds provide diverse ecosystems, mineral deposits, sources of water, and popular tourist attractions. The United States Department of Agriculture has assembled comprehensive plans on sustainable management of the Deep Creek River area, and numerous other websites ask visitors to take care of this land.

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Images 2 and 4 from Wikipedia sites, "List of hot springs in the United States" and "Deep Creek Hot Springs".

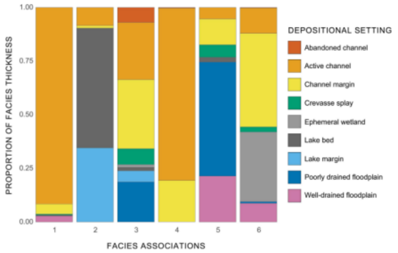
5.6 (6) Fossils of the Barstow Formation

Fossils of the Barstow Formation

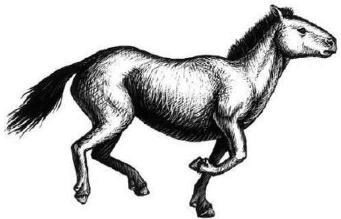
Eran Funaro

The Barstow Formation is a critical geological unit located in the Mud Hills and Rainbow Basin areas of the Mojave Desert, north of Barstow, California. It represents a remarkably complete sedimentary record spanning the medial portion of the Miocene epoch, with the oldest sediments dated to approximately 19 million years ago (Ma) and the youngest to around 13 Ma.

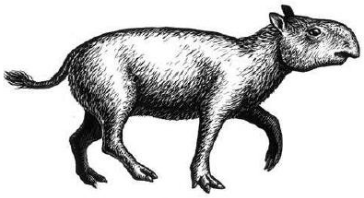
The formation consists of thousands of feet of sedimentary layers, which were deposited in a restricted basin fed by runoff from surrounding highlands. The sediments primarily represent three major depositional environments: alluvial fans, riverbeds, and lakebeds. The oldest member, the Owl Conglomerate, for instance, is composed of large clasts in a sandstone matrix, indicating deposition in an alluvial fan environment.



The Barstow Formation is globally renowned for its abundant and diverse fossil record. Its mammalian fauna is so significant that it is the type locality for the Barstovian Land Mammal Age of North America, which spans the period from 16 Ma to 12 Ma and is fondly known as NALMA.



Reconstruction of the three-toed horse Scaphohippus *(drawing by Katura Reynolds).*



Reconstruction of the oreodont, Brachycrus

The Fossil Mammals of the Barstow Formation

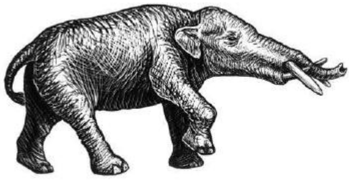
The sheer abundance and diversity of fossil mammals have made the Barstow Formation a cornerstone of Miocene paleontological study in North America.

Fossil collection in the area began as early as 1911. Early efforts were spearheaded by the University of California Museum of Paleontology at Berkeley, under the direction of J.C. Merriam from 1911 to 1919. A massive campaign of excavation was later conducted throughout the 1920s and 1930s by researchers from the laboratories of Childs Frick. Frick's collections, which were later bequeathed to the American Museum of Natural History, form the largest body of Barstow Formation fossils in the world today.

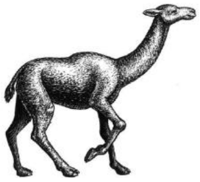
Major Faunal Groups

The fossil assemblage provides a detailed picture of medial Miocene life in the western United States. The megafauna (mammals larger than a rabbit) is dominated by a diverse array of herbivorous animals. Key groups found in the formation include:

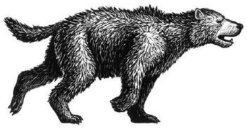
- Abundant horses
- Diverse groups of camels
- Antelope and deer-like taxa
- Rhinos
- Proboscideans (elephants)
- Merycoidodontidae
- Protoceratidae
- Tapiridae (Tapirs)
- Amphicyonidae ("Bear-dogs")
- And many more



Reconstruction o the elephant, f Gomphotherium



Reconstruction of the large camel, Aepycamelus

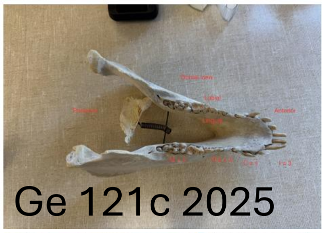


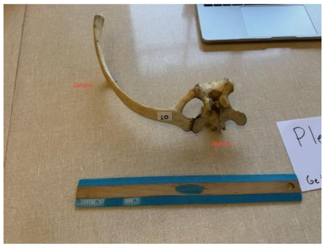
Reconstruction of the bear-dog, Amphicyon

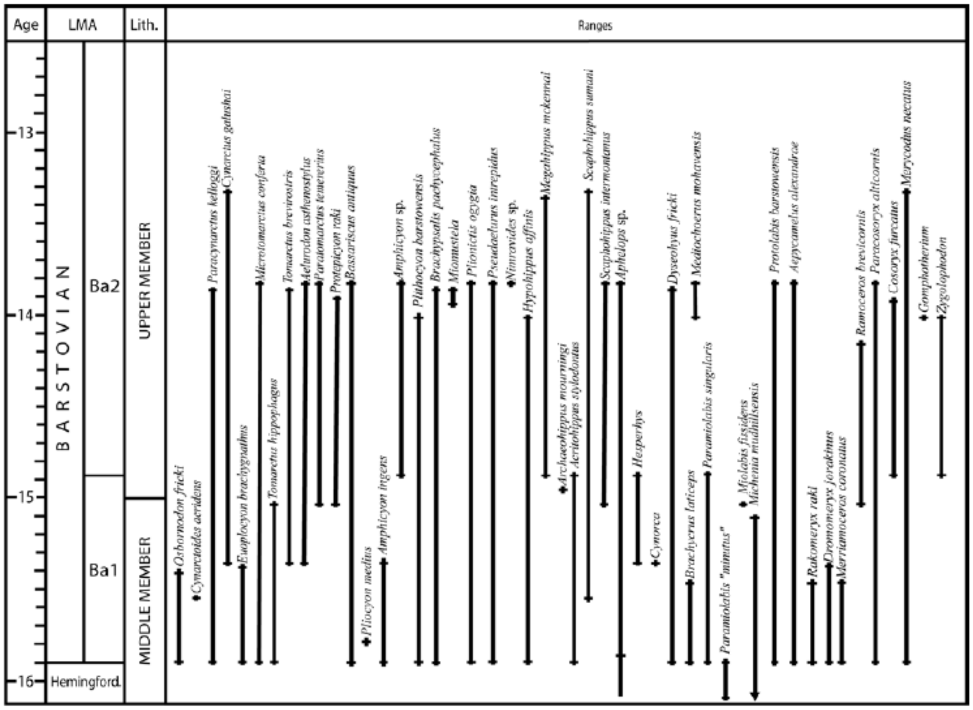
The 15 Ma Faunal Turnover

A significant evolutionary and environmental event is recorded in the Barstow Formation sediments: a major faunal turnover or extinction event that occurred between 15.5 - 15 million years ago.
A number of taxa became extinct at this time, including the deer-like *Rakomeryx*, the pronghorn antelope *Merriamoceros*, *Brachycrus*, and several species of camels such as *Paramiolabis* and *Michenia*.

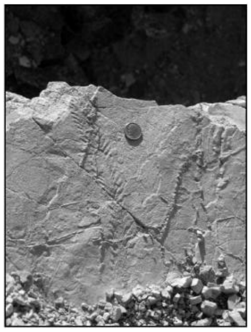
This extinction event coincided with a widespread floral change across the western United States. Prior to 15 Ma, the region was characterized by forests of deciduous hardwood trees and shrubs. A period of warming and decreased precipitation led to the replacement of this soft vegetation by plants with much tougher foliage, such as chaparral and sagebrush. A common factor among all the extinct mammals was their dental morphology: they all possessed low-crowned teeth adapted for processing soft vegetation. The increased occurrence of tough, coniferous vegetation was incompatible with their diet, leading to their extinction in the region.







Miocene Invertebrate Trackways in the Owl Canyon Area



In addition to its rich body fossil record, the Barstow Formation contains important trace fossils, or ichnofossils. Miocene invertebrate trackways were discovered in the Owl Canyon area of the Mud Hills during the inventory and replication of vertebrate trackways.

Preservation and Age

The trackways are preserved in a medium-grained tuffaceous limestone. The sediment that preserved the tracks was likely soft and fluid at the time of their creation, resulting in trackways that are generally poorly defined. The track-bearing layers are situated stratigraphically below the Skyline volcanic tuff, which is dated at 14.8 Ma. This positioning suggests the trackways themselves may be close to 15 million years old. They are also associated with fossilized plants and other organic materials.

Track Maker and Paleoenvironment

The track maker has not been definitively identified. The trackways form a row of tracks approximately 2 cm wide. While other arthropod body fossils (such as those of Palmer and Pierce) have been described from the Barstow Formation in the Calico Mountains, none appear large enough to have created the Owl Canyon tracks. However, the morphology of the trackways is considered similar to those made by certain arthropods, such as crayfish.

The environment of deposition for these trackways is interpreted as a repeatedly inundated lacustrine shoreline environment. Evidence for this includes the nature of the tuffaceous limestone, which suggests a freshwater lake system, and the presence of mud cracks, which indicate alternating periods of wetness and dryness. Ichnofossils like these are valuable for a detailed interpretation of depositional environments, as they directly record the movements of organisms where they lived.

The Raymond M. Alf Museum of Paleontology

A unique institution located in Claremont, California, as part of The Webb Schools. Established in 1968, it holds the distinction of being the only nationally accredited museum on a secondary school campus in the United States.

The museum owes its existence to teacher Raymond M. Alf, whose passion for paleontology led him to establish a research program involving his students. Since the late 1930s, fossil collecting trips for Webb students have been known as "Peccary Trips". These trips—many centered on Southern California locales like the Barstow Formation—allow students to engage in hands-on field work, including prospecting, quarrying, and screen-washing. The Alf Museum's collections are particularly recognized for their large array of fossil trackways, which is one of the most diverse collections of its kind in the world.

5.7 (7) Potential of Thermophiles in Industrial Processes

Potential of Thermophiles in Industrial Processes

Yurina Hashimoto (Ge136a 2025)

What are thermophiles and what are their features?

- Thermophiles (= heat-loving microbes) are microbes whose optimal growth temperature is higher than **45 degrees**.
- Thermophiles have **unique cellular features that enable them to endure higher temperatures**
  - membrane lipids with higher melting temperature (ex. tetraether, mono-layer lipid in some archaea)
  - thermostable enzymes (ex. Taq DNA polymerase used in PCR reactions is from thermophilic bacteria, *Thermus aquaticus*)
  - efficient DNA repair systems
  - overexpressed heat shock proteins
- Phylogenetically, **thermophiles are paraphyletic**, found in all three domains of life, but most commonly found in archaea.

How do thermophiles contribute to industrial processes? (Gallo et al., 2024)

1. Higher growth rate or yield at high temperature
   - Advantage of using thermophiles: Faster reaction kinetics
   - Example:
     - Efficient hydrogen production from cassava pulp at 60 degrees
     - Efficient methane production in anaerobic digester (Pason et al., 2020)
     - Enhanced lipid biosynthesis by thermophilic cyanobacteria and microalgae isolated from host springs (Singh & Kumar, 2022)
     - Enhanced production of EPS (extracellular polysaccharide) that are useful as antioxidant, anti-inflammatory, and antiviral properties (see section 3)

2. Production of thermostable products
   - Advantage of using thermophiles: Enzymes and metabolites from thermophiles can naturally maintain activity during harsh industrial processes at high temperatures without additional genetic modification
   - Examples:
     - Phycobiliproteins produced by thermophilic microalgae and cyanobacteria stable at elevated temperatures
       - Application: Phycobiliproteins from thermophiles could be utilized for food additives (natural dye) that require sterilization/pasteurization processes without losing their color
     - Thermostable esterases from *Brevibacillus thermoruber*, used in plastic degradation at high temperatures (Atanasova et al., 2021)

3. Special Topic: Nobel Prize in Physiology or Medicine 2025

- Nobel Prize in Physiology or Medicine 2025 was awarded to Mary E. Brunkow, Fred Ramsdell, and Shimon Sakaguchi for their discoveries concerning peripheral immune tolerance. (https://www.nobelprize.org/prizes/medicine/2025/press-release/)
- Especially, Shimon Sakaguchi made the key discovery on **regulatory T cells** in 1995
- **Regulatory T cells are not totally unrelated to thermophiles!**
  - (Gudmundsdottir et al., 2015) showed that EPS (Extracellular polysaccharides) produced by **thermotolerant *Cyanobacterium aponinum*** (Figure 1) from the Blue Lagoon hot springs in Iceland helps immune cells make IL-10 (Interleukin, functions in cell-cell communication in immune responses) and **may encourage the development of regulatory T cells**.
  - The authors mentioned that **EPS produced by *Cyanobacterium aponinum* may be useful as a modulator of immune responses**

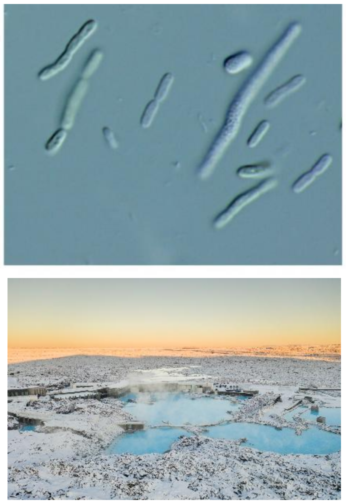


Figure 1. (top) Micrograph of *Cyanobactrium aponinum*. This strain grows up to 45-50 degrees. (bottom) Blue Lagoon. (Ref: 10.1007/s13205-014-0224-y. https://www.bluelagoon.com/stories/the-blue-lagoon-in-winter)

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5.8 (8) Mount Wilson Observatory

The Mount Wilson Observatory

Natalia Hernandez
Ge 136 FA 2025

Mt. Wilson is located on a 1,740m peak northeast of Pasadena. This location was originally chosen by the founder George Ellery Hale, due to the it elevation and proximity to Los Angeles which made it ideal for astronomy and interferometry. The inversion layer, which lies above the cooler air on top of the city, traps smog and warmer air and gets rid of turbulence. This creates stable, clear and dry conditions above the layer and enhances the visibility of telescopes.

Since it opened in 1904 its been on e of the most famous observatorie in the world, many major discoveries in astronomy happened here especially in the early 1900s when people were just starting to understand the vastness of universe. Today it is still used for research and public tours and is a big piece of science history in southern California.

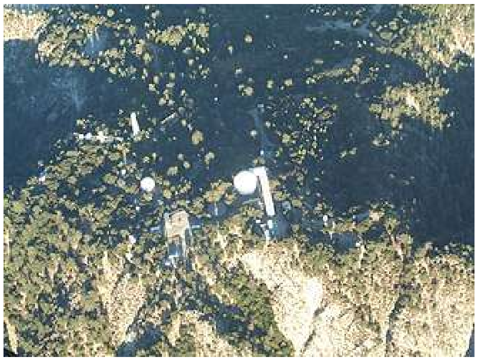

Figure 1: mt. Wilson observatory aerial view

History

Mount Wilson observatory was founded by George Ellery Hale in 1904. He chose the spot after hiking the San Gabriel mountains and realizing how perfect the night sky view and air conditions were. At the time it wasn't easy to build a large facility on top of a mountain and mules had to be used to haul materials.

The first big telescope, a 60-inch reflector, was finished in 1908 and was the largest telescope in the world at that time. Just a few years later in 1917, the 100-inch Hooker telescope was built by Hale and his team. For decades Mt. Wilson was home to the best and biggest telescopes in the world.

Telescopes

The first of Mt. Wilson's big telescopes was the 60-inch finished in 1908. Astronomers used it to study the brightness and composition of stars. In 1917 the 100in Hooker telescope was built. Becoming the most powerful telescope of its era, allowing astronomers to observe galaxies millions of light years away.

Using the Hooker telescope, Edwin Hubble discovered that the universe extends far beyond the milky way and that it is expanding. This finding transformed astronomy and led to the modern concept of an evolving universe. Earlier, Albert Michelson had used an interferometer attached to the telescope to make the first measurement s of a star's diameter, demonstrating the observatory's versatility for optical and experimental physics.

Mt. Wilson is also known for its solar telescopes, including the 60foot and 150 foot solar towers. These instruments are designed to track the sun's movement and study sunspots, solar flares, and magnetic activity. Data from these towers aided in understanding that sunspots are regions of intense magnetic fields and that solar activity follows approximately an 11year cycle. Which made the observatory the cornerstone of stellar and solar astronomy.

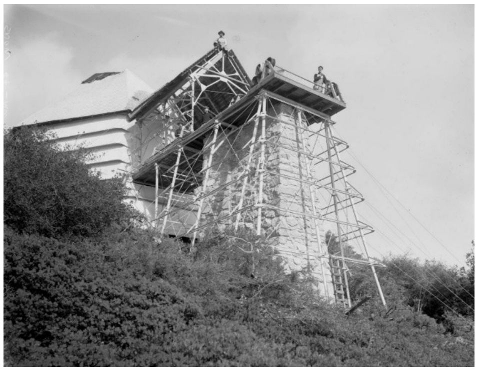

Figure 2: the Snow coelostat solar telescope

George Ellery Hale and his contributions

George Hale was an American astrophysicist who played a key role in establishing the observatory, as well as shaping Caltech. Hale's early work included solar observations and instrumentation. He understood that to make major advances in astronomy larger telescopes and better sites were required.

At mt. Wilson Hale oversaw construction of both telescopes which became world-class in his leadership. He also helped transform the vocational Throop college in Pasadena into Caltech by recruiting key scientists and helped elevate the institute into a major center of science and engineering. Through his work, Hale left a lasting legacy: large scale telescope design, prime observing locations, and strong institutional foundation for astronomy.

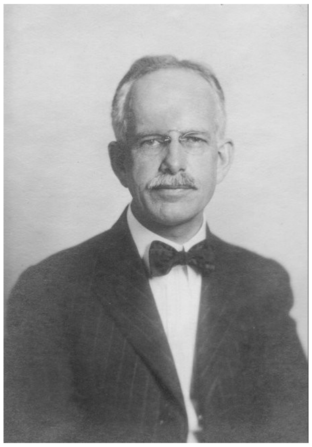

Figure 3: George Ellery Hale (1868-1938)

Modern Role

Although mt. Wilson is no longer the world's leading research observatory, it still plays an active role in science and education. The 60-inch telescope continues to operate and is available for public observing nights. The Hooker telescope is still used for specialized pojects such as optical interferometry and forms part of the CHARA array—a network of 6 telescopes that work together to study stars in detail. The observatory's coelostats still monitor the sun and contribute to research in solar cycles and influence of solar activity on our climate.

In addition to ongoing research, the observatory has become a center for outreach, science education, and public astronomy events that focus on space exploration.

5.9 (9) Kelso Dunes

Kelso Dunes: Formation and Human Usage

Abby Keebler

The Kelso Dune field spans approximately 45 square miles within Mojave National Preserve and has both inactive/vegetated dunes and inactive, unvegetated dunes, the tallest of which is approximately 500 ft above the desert floor. They are a popular tourist attraction, a habitat for unique desert flora and fauna, and an indicator of past hydrogeologic processes in the Mojave.

Sediment Source and Dune Formation

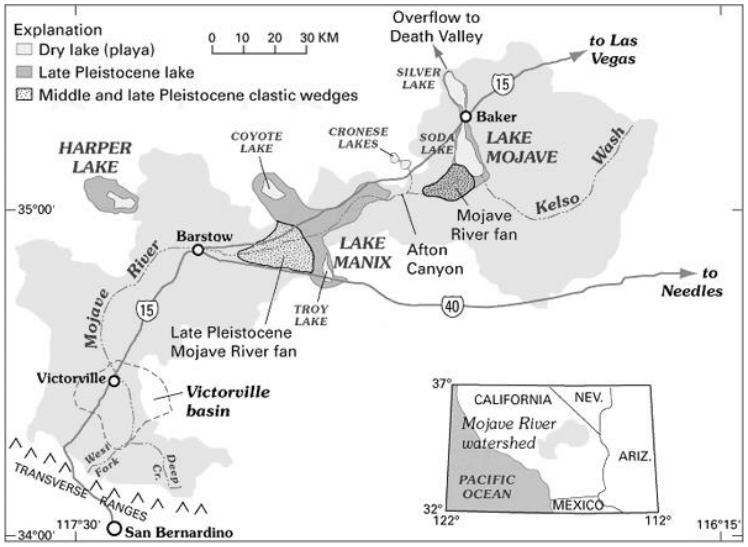
Explanation
Dry lake (playa)
Late Pleistocene lake
Middle and late Pleistocene clastic wedges
0 10 20 30 KM
Overflow to Death Valley
to Las Vegas
SILVER LAKE
15
Baker
HARPER LAKE
COYOTE LAKE
CRONESE LAKES
SODA LAKE
LAKE MOJAVE
Wash
Kelso
Mojave River fan
35°00'
Barstow
LAKE MANIX
Afton Canyon
to Needles
River
Mojave
15
40
TROY LAKE
Late Pleistocene Mojave River fan
Victorville
Victorville basin
37°
CALIFORNIA
NEV.
Mojave River watershed
ARIZ.
PACIFIC OCEAN
MEXICO
32°
122°
112°
116°15'
West Fork
Deep Cr.
TRANSVERSE RANGES
117°30'
San Bernardino
34°00'

Figure 1: map of ancestral Mojave River watershed [2]

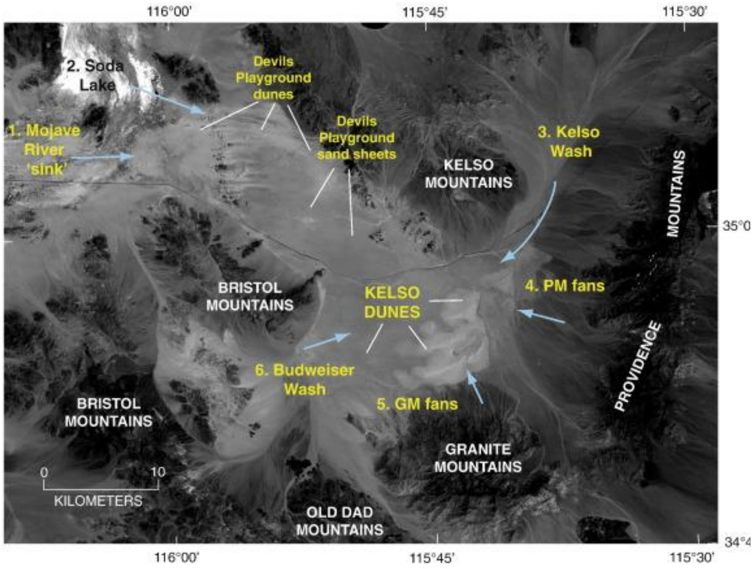
116°00'
115°45'
115°30'
2. Soda Lake
Devils Playground dunes
1. Mojave River 'sink'
Devils Playground sand sheets
3. Kelso Wash
KELSO MOUNTAINS
MOUNTAINS
35°0
BRISTOL MOUNTAINS
KELSO DUNES
4. PM fans
PROVIDENCE
6. Budweiser Wash
5. GM fans
BRISTOL MOUNTAINS
GRANITE MOUNTAINS
0 10
KILOMETERS
OLD DAD MOUNTAINS
34°4

Figure 2: Landsat ETM+ image of Kelso Dunes and surrounding area with sediment sources and mountain ranges labeled [3]

Dune formation requires a sediment source, a process by which to weather and sort sediment into sand-sized particles, and a wind regime capable of transporting the sand (until it isn't, and thus drops the sand, forming the dune). Kelso Dunes' primary sediment source is the San Bernardino mountains, which consist primarily of felsic igneous rocks rich in quartz and feldspar. San Bernardino sediments were transported by the ancestral Mojave River, which began flowing ~2-5 million years ago and flowed from southwest to northeast (Fig. 2). It initially emptied into Lake Manix, which was approximately 90 square miles and is located east of present-day Barstow [2]. In the late Pleistocene, Lake Manix drained as the Mojave River began to flow further east, creating Lake Mojave, which is present-day Soda Lake and Silver Lake (both dry playas). Eventually, the Mojave River migrated to flow primarily underground, leaving a bunch of alluvium and playas bearing fine-grained sediments which can be entrained and transported by wind [1,2].

Though Mojave River alluvium is a primary source of sediment for Kelso dunes, K/Rb and K/Ba geochemical data on K-feldspar collected in different sections of the dune field support sediment sourced from weathering of surrounding ranges like the Providence Mountains as well [3]. Winds transport sediments to the location of Kelso Dunes, where eddies and crosswinds caused by the Granite and Providence Mountains cause sand carried by the wind to fall out of suspension, creating the deposit [1].

Dune Morphology

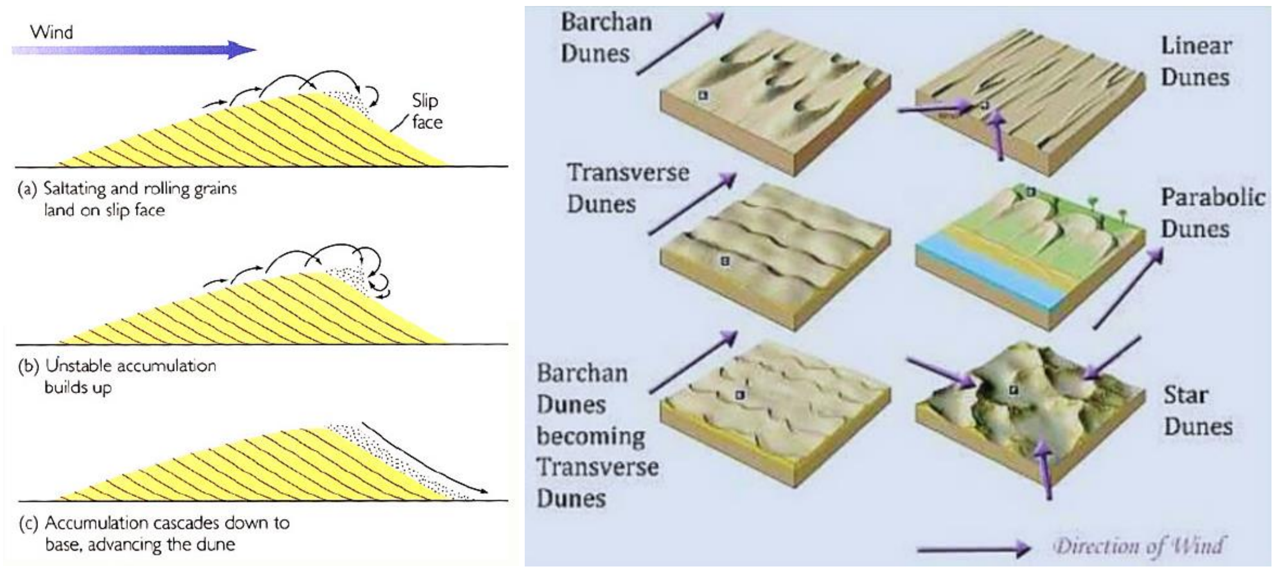
Wind
Slip face
(a) Saltating and rolling grains land on slip face
(b) Unstable accumulation builds up
(c) Accumulation cascades down to base, advancing the dune
Barchan Dunes
Linear Dunes
Transverse Dunes
Parabolic Dunes
Barchan Dunes becoming Transverse Dunes
Star Dunes
Direction of Wind

Figure 3: dune migration and interior structure ; dune shapes resulting from varying sediment availability and wind regime [4]

Human Usage

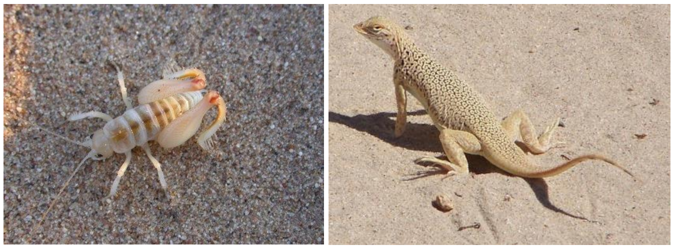

Figure 4: some of the critters you can find in the dunes [6]

Human use of the dunes once including mining: the USGS Mineral Resources Data System records a Kelso Dunes Mine, alternately known as the Black Sands Mine. They primarily mined silica, with gold, iron, and titanium as tertiary products [5]. Today, Kelso Dunes are the most popular hike in Mojave National Preserve [1]. The Kelso Dunes Trail is approximately 1.5 miles from trailhead to summit with approximately 500 feet of elevation gain. Hikers enjoy the panoramic views from dune crests, if not the strenuous hike up. Hikers can look for Kelso Dunes' endemic insect species, including the Kelso giant sand treader cricket, as well as the rare Mojave fringe-toed lizard [1].

Kelso Dunes are also exciting to visit because they can "sing," a phenomenon in which very tall dunes made of round, uniformly sized grains create resonant booming sounds. When sand avalanches down slip faces of such dunes on hot days, it generates linear waves which travel volumetrically inside the dunes and reflect off hard internal layers, which amplifies and sustains the sounds [7]. In general, singing dunes may resonate for up to 15 minutes from a single sand cascade, and the sound can be heard for miles. On exceptionally hot days, hikers may attempt to trigger this phenomenon at Kelso themselves by climbing up the dunes and triggering avalanches from the crest down the slip faces.

Works Cited
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5.10 (10) Los Angeles Climate

Los Angeles Climate Controls:
Marine layer, High Desert Wind and Heat dome

Ting-Juan Liao

What is Marine layer?

The marine layer is an air mass that forms when cool, moist air from over a large body of water is trapped beneath a layer of warmer, drier air. The process begins when air directly above a cool ocean surface is chilled by the water below. This creates a cool, dense layer of air. Above it, the air remains warmer and less dense. This scenario, where temperature increases with altitude, is called a temperature inversion. Because the cool air is denser, it gets trapped by the warmer “lid” of air above it. As moisture evaporates from the water's surface, the humidity within this trapped layer increases. When the humidity reaches 100%, the water vapor condenses, forming the characteristic fog or low-lying stratus clouds associated with the marine layer. This layer typically disperses when either strong winds mix the air masses or when the sun’s heat warms the surface enough to break down the temperature inversion.

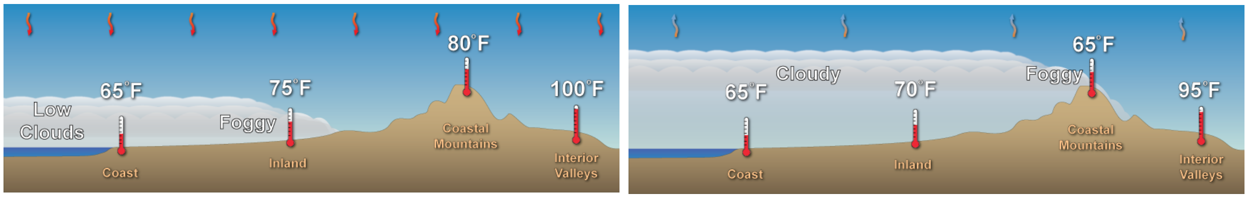

Figure 1. Left: Originating over the ocean, the marine layer moves inland when the high-pressure system above it weakens, allowing the cool air mass to spread. Right: As the marine layer reaches the coast, it is forced upward by mountains. (NOAA)

June Gloom: Marine layer in Southern California

In Southern California, the California Current brings cold water from the northern Pacific, creating ideal conditions for a marine layer to form. While this can occur throughout the year, it is most prominent in late spring, leading to the well-known “May Gray” and “June Gloom.” This happens because the temperature contrast between the cool ocean and the rapidly heating inland areas is at its peak.

Once the marine layer forms, prevailing westerly winds push the clouds and fog inland in a process called advection. This inland push continues until the air mass is blocked by coastal mountain ranges. The marine layer is usually strongest around dawn, when the land has cooled overnight, maximizing the temperature difference that strengthens the inversion. A strong marine layer is actually sustained by a persistent high-pressure system over the ocean. This high pressure creates the powerful temperature inversion that acts like a lid, trapping the cool, moist air. Conversely, a passing low-pressure system typically brings instability that weakens or clears out the marine layer.

Figure 2. June Gloom at Seal Beach in late morning, June 2013. (Wikipedia)

Foehn wind

A Foehn wind is a type of warm, dry wind that flows down the leeward (downwind) side of a mountain range. The warmth and dryness are a result of the air losing its moisture and being heated through compression. As prevailing winds push moist air up the windward slope of a mountain, the air expands and cools. When it cools to its dew point, the water vapor condenses, forming clouds and releasing precipitation (rain or snow). This process of condensation also releases latent heat, causing the air to cool at a slower pace, known as the moist adiabatic lapse rate. After crossing the mountain crest, the now-dry air sinks down the leeward slope. This descent compresses the air, causing it to warm up rapidly. This process is called adiabatic warming. Since the air is now dry, it warms at the faster dry adiabatic lapse rate.

High Desert Wind (Santa Ana Wind)

The Santa Ana wind is a classic example of a foehn wind specific to Southern California. It begins when a strong high-pressure system forms over the Great Basin. This system forces dry desert air to flow towards the coast, funneling through and over the region's mountain ranges, shown as figure 4. As this air descends from the high desert to sea level, it undergoes intense compression, which significantly heats the air and lowers its humidity. This process transforms the air, resulting in the powerful, hot, and exceptionally dry winds known as the Santa Anas.

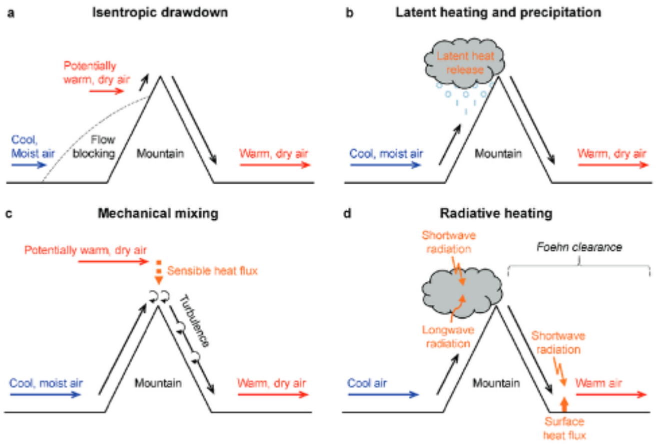
a
Isentropic drawdown
Potentially warm, dry air
Cool, Moist air
Flow blocking
Mountain
Warm, dry air
b
Latent heating and precipitation
Latent heat release
Cool, moist air
Mountain
Warm, dry air
c
Mechanical mixing
Potentially warm, dry air
Sensible heat flux
Turbulence
Cool, moist air
Mountain
Warm, dry air
d
Radiative heating
Shortwave radiation
Foehn clearance
Longwave radiation
Shortwave radiation
Cool air
Mountain
Warm air
Surface heat flux

Figure 3. Four different mechanisms of foehn wind. (Andrew D. et. al.)

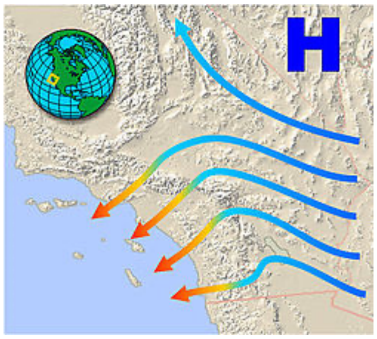

Figure 4. Illustration of high-pressure area over Great Basin and Santa Ana wind. (wiki)

Heat dome, Basin effect, and Urban heat island effect

Los Angels is located in a coastal basin, a bowl-like area surrounded by mountains. This geography naturally traps air and restricts its circulation. A strong high-pressure system, known as a heat dome, settles over the region. The dome acts like a lid, causing the air to sink and heat up while also suppressing or completely blocking the cool, moist marine layer from moving inland. This intense heat is then amplified by the Urban Heat Island effect. The vast surfaces of concrete and asphalt absorb enormous amounts of heat during the day and radiate it back slowly all night. This prevents the city from cooling down, making heatwaves feel relentless and increasingly dangerous.

All together in LA?!

The strength of the high-pressure system is the deciding factor for Southern California's weather. When it's strong, a heat dome dominates, suppressing the marine layer and causing hot, dry conditions. Conversely, as the high pressure weakens, the marine layer can advance inland again, bringing back cooler, more humid weather with clouds and fog. This constant push and pull is the defining characteristic of our autumn climate.

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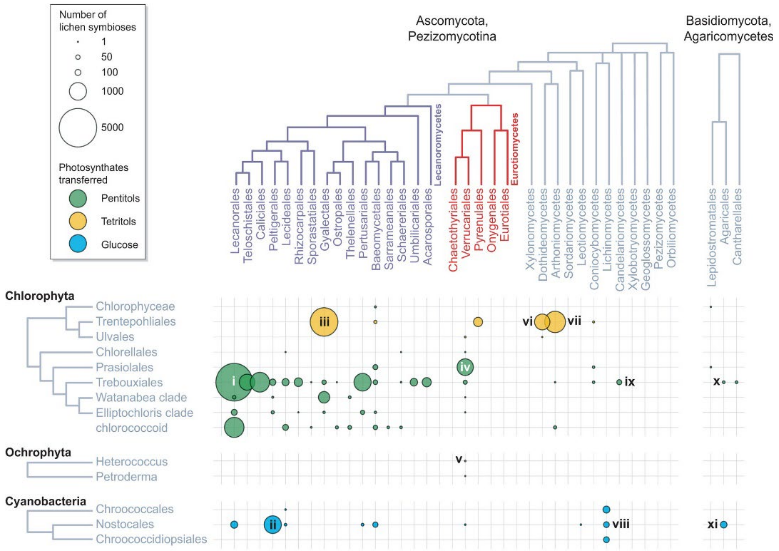
5.11 (11) Common American Southwest Lichens

Common American Southwest Lichens

Forrest McCann

Lichens are a symbiosis

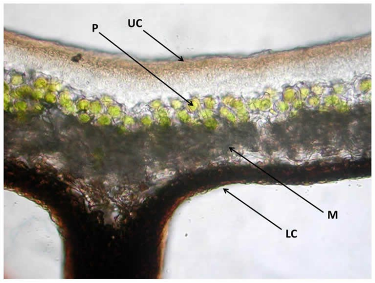


Lichens are among the oldest recognized evolutionary symbioses [1] and are canonically described as a symbiosis between a mycobiont (a fungi) and a photobiont (a green alga or a cyanobacterium). The earliest fossil evidence of lichen (specifically ascomycete lichen) is ~415 million years and molecular phylogenies suggest the lichenization of fungi have happened multiple times [2]. Of the over 19,000 described lichens, more than half are a partnership between a *Lecanoromycetes* fungi and a *Trebouxiales* or *Trentepohliales* algae [3]. The notion of a 'binary' symbiosis between an alga and an ascomycete fungus continues to be challenged with the advent of culture-independent sequencing techniques that elucidate what taxa comprise lichen [4]. The host fungi display greater richness including the surprising finding that members of the basidiomycetes appear omnipresent and necessary for thallus development [4]. Also, there exists a substantial diversity of lichen-associated bacteria that display a community structure specific to different species of lichen [5–8], raising basic questions about the function and natural history of these microbial taxa in the symbiosis. Are they tightly conserved evolutionary partners or opportunistic bacteria from the local environment? The extent to which lichen-associated bacteria are obligate to lichen symbiosis or how such relationships might have evolved remains poorly understood and understudied.

The lichen symbiosis is commonly described as "fungi that have discovered agriculture" (Trevor Goward). The carbohydrate currency between the fungi and photobionts are polyol (multiple -OHs). Algal symbionts export polyols (e.g. ribitol) and many cyanobacteria export glucose that is converted into polyols (e.g. mannitol) [3]. Two models for the lichen symbiosis exist: the nutritional model and the anhydrobiosis model. The nutritional model claims that the fungi use carbon fixed by phototrophs for growth and respiration, while the anhydrobiosis model claims fungi use phototroph-fixed carbon only for protecting cell function during desiccation [3]. However, many lichenologists believe in a hybrid model that claim the fungi partition phototroph fixed carbon into one pool for respiration and growth, and another for desiccation protection [3].

Lichen Morphology

- Foliose: leaf like lichen, has upper and lower surface
- Fruticose: erect or pendant or hair like lichen, no clear upper/lower surface
- Crustose: crust like lichen
- Squamulose: scale like liken, between crustose and foliose lichens
- Thallus: vegetative body of the lichen
- Hyphae: filamentous fungal structure, can be branched
- Rhizine: root-like structure on lichen
- Lobes: ends of lichen
- Medulla: inside of lichen, contains hyphae and photobionts
- Cortex: outside of lichen
- Apothecia: disks/cups of spores
- Pruinose/pruina: clumps of dead fungal cells/crystals, looks frosted, powdered, dusted. Can be white or colored
- Soredia: balls of hyphae that have innards, does not have a cortex, can be fine/powdery -> grain-like (farinose -> granulose)
- Isidia: tiny cylindrical/granular outgrowths, has a cortex
- Granules/Blastidia: rounded balls that bud/lob off, blastidia are small granules (hard to distinguish from soredia)
- Schizidia: flaps that split off for reproduction



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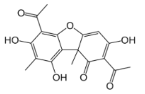
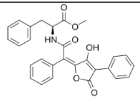
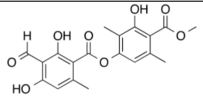


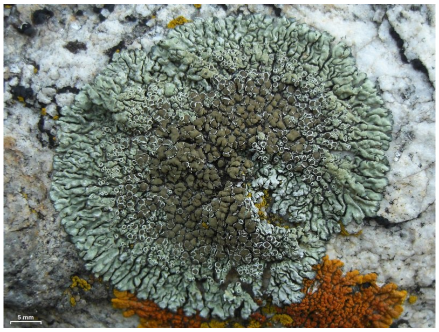
Usnic Acid
bright green,
UV/antibiotic

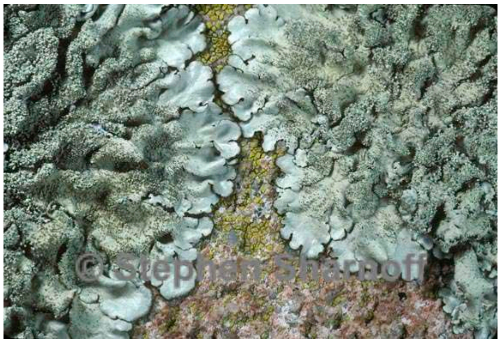


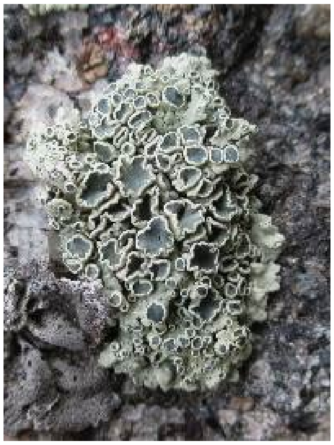
Rhizocarpic
Acid
yellow, UV



Atranorin
gray/green,
UV







Lecanora garovaglii and Lecanora sierrae (sagebrush rim lichen):

Habitat: Rocks, especially sandstone, common in sagebrush/juniper brush areas

Description: Thallus is yellow-green to pale green if thick white prunia, often blackening at the lobes, lobes are thick and sinuous quite convex except at tips, apothecia are pale yellowish brown to dark yellowish brown.

Xanthoparmelia mexicana (salted rock shield):

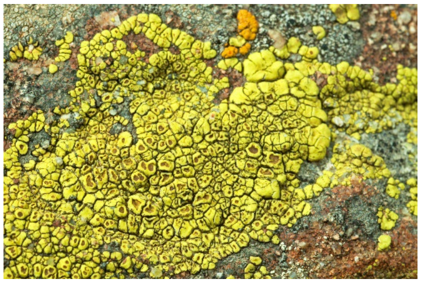
Habitat: exposed rocks in pine/oak scrub

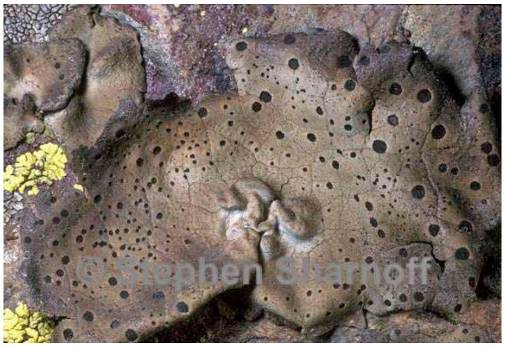
Description: Thallus closely or loosely attached to rock, often shiny at lobe tips (1.5-5 mm), dense globose isidia that can become cylindrical or branched, lower surface pale brown or smokey gray at edges, apothecia rare

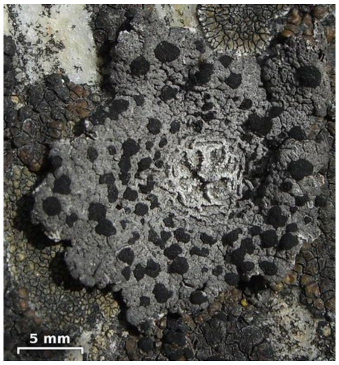
Rhizoplaca melanophthalma (green rock possy):

Habitat: exposed rocks, usually Ca poor but not strict

Description: Thallus light to army green, usually raised and buttonlike, cups can be undulating, lower surface is smooth to rough and uneven, umbilicate.







Acarospora socialis (bright cobblestone lichen):

Description: yellow to yellow-green, crustose to squamulose, thallus of squamules with stipe, indeterminate, contiguous or dispersed. squamules usually 0.5-1.5 mm wide,

Umbilicaria phaea (emery rock trip):

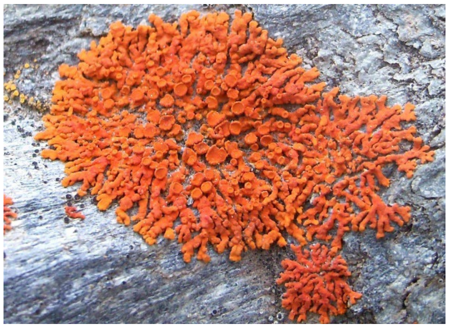
Habitat: exposed rocks in arid sites

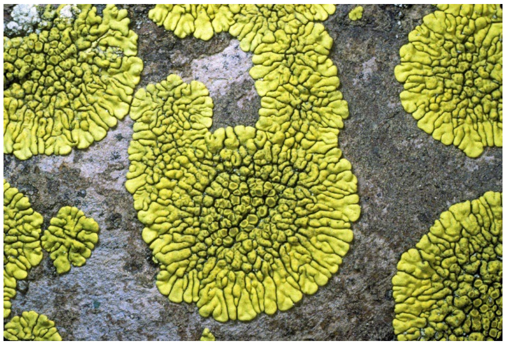
Description: thallus, smooth, rather shiny and single lobed, up to 6cm wide, lower surface pale rough and papillate emery cloth like, apothecia common and partially embedded angular, disks have concentric ridges

Umbilicaria krascheninnikovii and *Umbilicaria polaris* (salty rock trip):

Habitat: exposed rock in the alpine

Description: thallus black to dark gray-brown (1.5-4 cm), heavily encrusted with salt-like white deposits, high sharp ridges, lower surface smooth pale brown to pink, mouse gray at edges and pruinose edges, apothecia slightly stalked prominent black margins has irregular fissures or ridges in center





Xanthoria elegans (elegant sunburst lichen):

Description: foliose, forming small to large rosettes up to 6 cm wide, common to have cups, but not always, do not have sordia

Pleopsidium flavum:

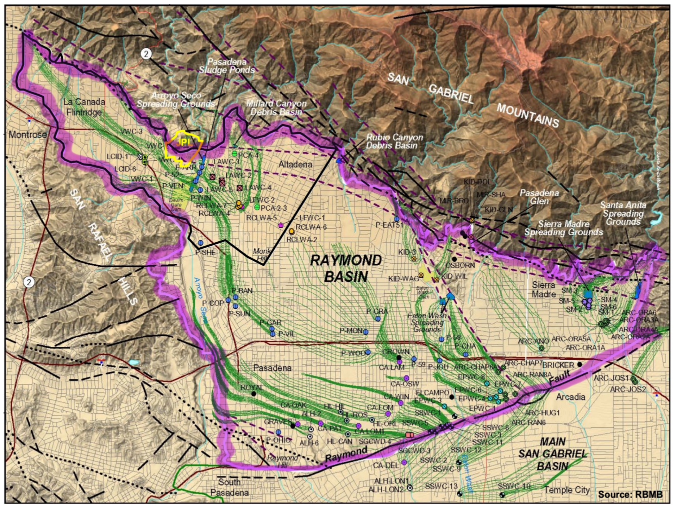
Description: crustose, bright yellow/green, shiny, rough upper surface, grows on granitic rocks, especially under

5.12 (12) Raymond Basin

The Raymond Groundwater Basin

Pasadena's local (minority) water supply

Ruth Moorman • Ge136a • October 24th – 26th 2025


SAN GABRIEL MOUNTAINS
RAYMOND BASIN
MAIN SAN GABRIEL BASIN
SAN RAFAEL HILLS
Raymond Fault
Pasadena Sludge Ponds
Arroyo Seco Spreading Grounds
Millard Canyon Debris Basin
Rubio Canyon Debris Basin
Pasadena Glen
Sierra Madre Spreading Grounds
Santa Anita Spreading Grounds
Eaton Wash Spreading Grounds
La Canada Flintridge
Montrose
Altadena
Pasadena
Sierra Madre
Arcadia
South Pasadena
Temple City
Source: RBMB

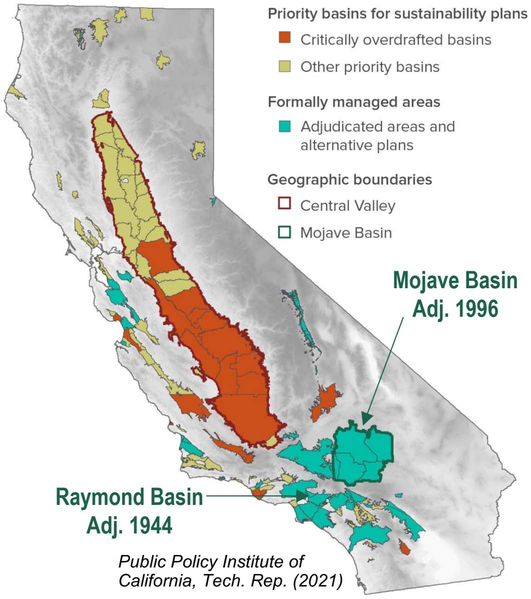
NASA, Tech. Rep. (2007). Green lines indicate simulated trajectories of particles that ultimately reach monitoring wells (colored circles). Basin outline emphasis added.

Physical Context

The Raymond basin is a 26,200 acre (~40 square mile) groundwater basin beneath Pasadena and surrounding municipalities. The water bearing materials of the basin are mostly Quaternary alluvium, deposited into alluvial fan structures by streamflow from the San Gabriel Mountains. The basin is bound to the north and west by contacts with basement rocks of the San Gabriel Mountains and San Rafael Hills and is separated from the much larger (255 square miles) San Gabriel Valley groundwater basin to the south by the Raymond fault. The Raymond fault acts as a barrier to flow in the west but allows unconstrained discharge into the San Gabriel Valley basin towards the east. The basin is naturally recharged by percolation of local precipitation and streamflow from the San Gabriel Mountains. Natural recharge is amplified using "spreading grounds" where local runoff (LA River diversion) and/or imported water (MWD purchases) is held in place long enough to percolate.

Adjudication

The Raymond groundwater basin is one of California's 34 **"adjudicated"** groundwater basins, meaning that a court settlement between extractors has established explicit (and tradeable) extraction rights of parties that are monitored by a court appointed "watermaster". Groundwater management is a bit of wilderness outside these adjudicated regions, which are mostly in SoCal.


Priority basins for sustainability plans
🟥 Critically overdrafted basins
🟨 Other priority basins
Formally managed areas
🟩 Adjudicated areas and alternative plans
Geographic boundaries
☐ Central Valley
☐ Mojave Basin
Mojave Basin Adj. 1996
Raymond Basin Adj. 1944

Public Policy Institute of California, Tech. Rep. (2021)

Path to Adjudication

First wells drilled	**1881**
Overdraft of basin begins	**1913**
Excessive extraction and limited recharge lead to well failures and increasing pumping expenses	**1924**
Pasadena granted permits to divert 4,000 AF† per year from the San Gabriel River (SGR)	**1928**
Pasadena votes to construct Morris Dam on SGR	**1929**
Pasadena sued by San Gabriel Valley over dam plans. Resolution involves MWD* promising to purchase dam following Colorado River diversion	**1932**
Pasadena initiates superior court proceedings against Alhambra, this led to the first basin wide adjudication of groundwater rights in California	**1937**
Court directed independent referee characterizes basin "safe yield" at 21,900 AF annually, meaning the basin had been in overdraft by (on average) ~7,000 AF or 33% annual safe yield every year since 1913	**1943**
Allocations based on downscaling historical use rates such that the aggregate use matched "safe yield". **Judgement signed 1944** (appeals until1949).	**1944**
Amended with new "safe yield" estimate of 30,622 AF per year (a 40% increase!), still in use.	**1955**
Amended to allow extractors to credit spreading.	**1974**

*MWD = Metropolitan Water District of Southern California, †AF = acre feet

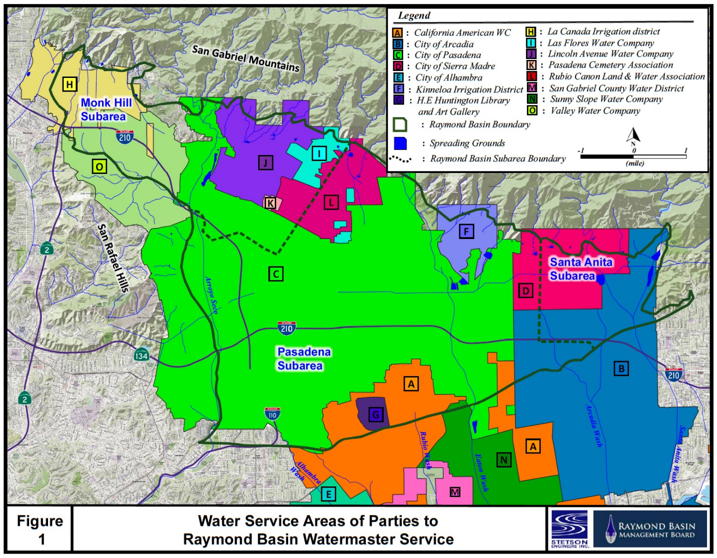
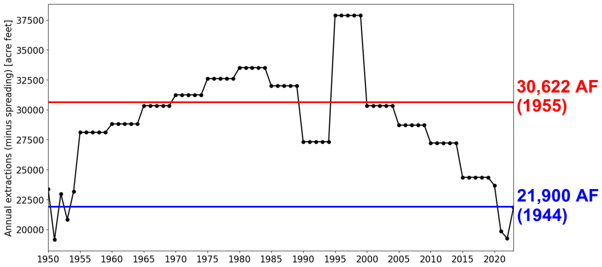

Legend
A : California American WC
B : City of Arcadia
C : City of Pasadena
D : City of Sierra Madre
E : City of Alhambra
F : Kinneloa Irrigation District
G : H.E Huntington Library and Art Gallery
H : La Canada Irrigation district
I : Las Flores Water Company
J : Lincoln Avenue Water Company
K : Pasadena Cemetery Association
L : Rubio Canon Land & Water Association
M : San Gabriel County Water District
N : Sunny Slope Water Company
O : Valley Water Company
: Raymond Basin Boundary
: Spreading Grounds
: Raymond Basin Subarea Boundary
N
-1 0 1
(mile)
San Gabriel Mountains
Monk Hill Subarea
Santa Anita Subarea
Pasadena Subarea
San Rafael Hills
STETSON ENGINEERS INC.
RAYMOND BASIN MANAGEMENT BOARD

Figure 1 Water Service Areas of Parties to Raymond Basin Watermaster Service

RBMB 2023-24 Annual Report

Current Management

Allocations between the 15 extractor parties (see map) are managed by the **Raymond Basin Management Board**. Allocations are mostly still nominally capped at the 1955 estimated "safe yield" of 30,622 AF per year but have been modified periodically in response to drought conditions. Since the 1970s, parties have been able to offset extraction with "spreading ground" use.



Reported annual extractions (less spreading), data from RBMB 2023-24 Annual Report (mostly 5 year means)

The JPL Superfund Site…

So… the Raymond basin contains a "superfund" site. Historic JPL activities in the 1940s and 1950s, primarily solid rocket fuel testing, resulted in contamination of the proximal Monk Hill subarea and potentially (though analysis makes this appear unlikely) parts of downstream Pasadena subarea with **perchlorate**. The primary cause for concern is potential thyroid inhibition. This contaminant was first identified as an issue in the basin in 1997 and long-term cleanup efforts are ongoing. Cleanup activities predominantly involve pumping, above ground treatment, and reinjection at three JPL facilities.

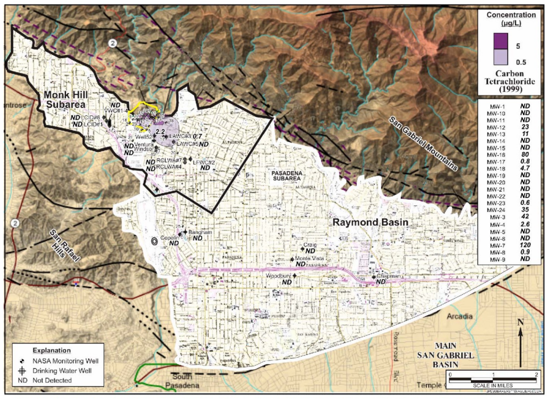

Concentration (µg/L)
5
0.5
Carbon Tetrachloride (1999)
Monk Hill Subarea
Pasadena Subarea
Raymond Basin
San Gabriel Mountains
San Rafael Hills
Arcadia
MAIN SAN GABRIEL BASIN
South Pasadena
Temple
N
Explanation
NASA Monitoring Well
Drinking Water Well
ND Not Detected

Figure: carbon tetrachloride is considered a tracer for the JPL sourced contaminants.

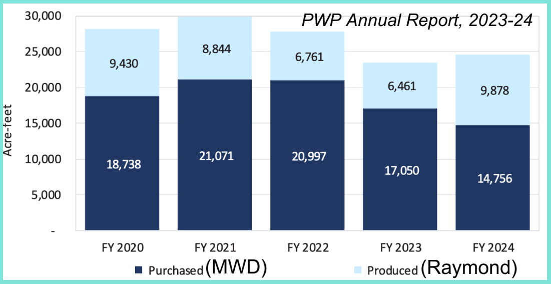
Sources

Information presented comes from the following sources (all government agency reports):

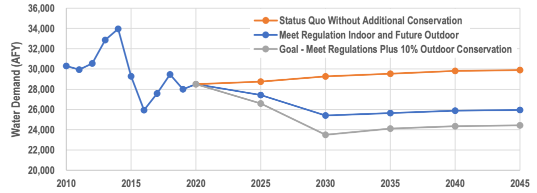
1. *Raymond Basin Management Board Annual Report 2023-24, published Sept 2024.*
2. *NASA JPL EPA ID# CA9800013030 Technical Memorandum, published Jan 2007.*
3. *Pasadena Department of Water and Power Water System and Resources Plan, published Sept 2021.*
4. *Pasadena Department of Water and Power Annual Report Fiscal Year 2024.*

Pasadena's Water Sources

Though the City of Pasadena has the largest decreed right to extraction of all users in the Raymond basin adjudication, 12,807 AF per year (split between the Pasadena and Monk Hill subareas) or 42% of the total claim, the City of Pasadena only gets about a third of its water needs from the Raymond groundwater basin. **The remaining 2/3rds of Pasadena's water needs are purchased from the *Metropolitan Water District of Southern California* (MWD) which imports water from the Colorado River (via the Colorado River Aqueduct) and Northern California (via the California Aqueduct).**



Pasadena Water and Power (PWP) planning reports indicate a desire to reduce reliance on imported water, with a portfolio of 50% imported, 50% Raymond basin water preferred. It appears the plan to achieve this split involves increased pumping and artificial recharge capacity alongside usage decrease.



5.13 (13) The Geology of Dish Hill and Mantle Xenoliths

The Geology of Dish Hill and What the Mantle Xenoliths tell us

Sophia Ji-In Ree Ge136a Fall 2025

Geological Background of Dish Hill and the Mojave region

Dish Hill is a Plio-Pleistocene[5Ma-12ka] cinder cone (the most common type of volcanoes) in the southern Mojave desert well known for the abundant occurrence of mantle xenoliths. The Mojave region (Figure 1) forms part of the Cretaceous North American Cordilleran Batholithic Belt (Figure 2), which developed as the Farallon Plate subducted under the North American Plate. This region is a key area for understanding the complex evolutionary history of the North American Cordillera.

The Mojave region was developed in a unique paleogeographic setting where the Mesozoic active continental margin formed along a major transform system that cut into the stable North American cratonic lithosphere. This geometry placed arc magmatism directly along the edge of a craton. (A craton is a large, very stable, and ancient part of the continental crust.) This is a rare situation where interaction between the old, refractory mantle and younger subarc mantle were possible. The currently structurally disrupted state of the Mojave region is due to flat subduction of the Farallon Plate during the late Cretaceous. It has been hypothesized to remove some of the cratonic roots by tectonic erosion. However, the current mantle >60 km is thought to be a result of subsequent rethickening.

The Mojave region represents a transitional zone between stable continental crust and the tectonically active plate margin, preserving evidence of both ancient cratonic roots and and rejuvenated mantle formed through subduction and later tectonic reconstruction.

Much of this history has been revealed through studies of the mantle xenoliths brought to the surface through volcanism from the Oligocene to the present. They are found at various volcanic fields within the Mojave region including the Dish Hill! (e.g. Figure 3, a reconstruction of the cross section of the mantle based on petrological description of mantle xenoliths)

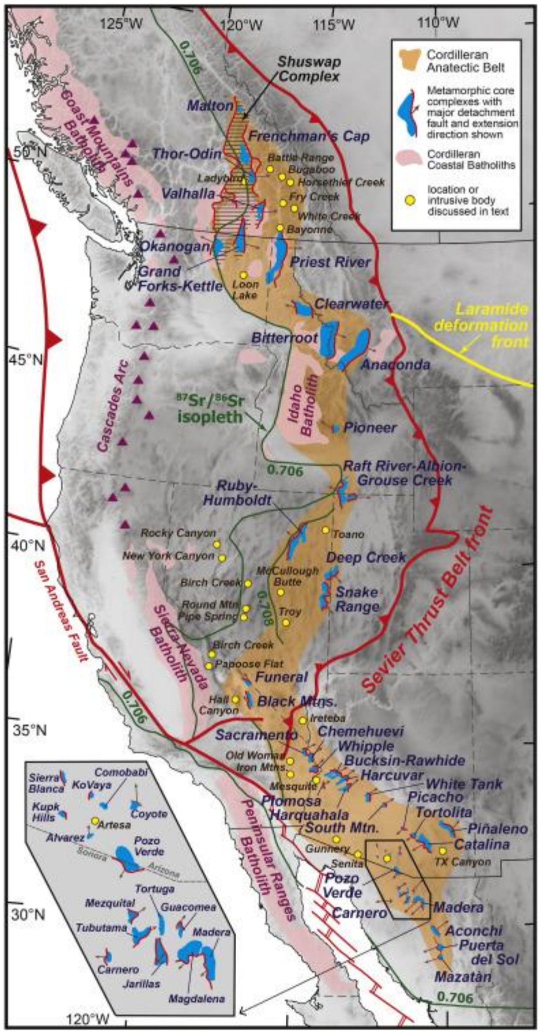

125°W
120°W
115°W
110°W
50°N
45°N
40°N
35°N
30°N
120°W
Cordilleran Anatectic Belt
Metamorphic core complexes with major detachment fault and extension direction shown
Cordilleran Coastal Batholiths
location or intrusive body discussed in text
Shuswap Complex
Malton
Frenchman's Cap
Thor-Odin
Valhalla
Okanogan
Grand Forks-Kettle
Priest River
Clearwater
Bitterroot
Anaconda
Laramide deformation front
Coast Mountains Batholith
Cascades Arc
^{87}Sr/^{86}Sr isopleth
0.706
Idaho Batholith
Pioneer
Raft River-Albion-Grouse Creek
Ruby-Humboldt
Deep Creek
Snake Range
Sevier Thrust Belt front
San Andreas Fault
Sierra Nevada Batholith
Funeral
Black Mtns.
Sacramento
Chemehuevi
Whipple
Bucksin-Rawhide
Harcuvar
White Tank
Picacho
Tortolita
Piñaleno
Catalina
Plomosa
Harquahala
South Mtn.
Peninsular Ranges Batholith
Pozo Verde
Carnero
Madera
Aconchi
Puerta del Sol
Mazatán
0.708
Sierra Blanca
KoVaya
Comobabi
Kupk Hills
Artesa
Coyote
Alvarez
Sonora
Arizona
Mezquital
Tortuga
Guacomea
Tubutama
Carnero
Jarillas
Magdalena

Figure 2. [Chapman et al., 2021]
Overview map of the North American Cordilleran Belt

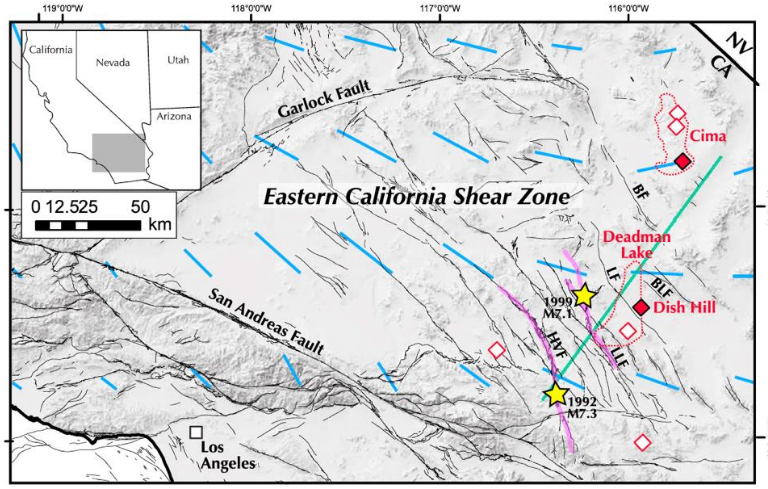

119°0'0"W
118°0'0"W
117°0'0"W
116°0'0"W
35°0'0"N
34°0'0"N
California
Nevada
Utah
Arizona
0 12.525 50 km
NV
CA
Garlock Fault
Cima
Eastern California Shear Zone
BF
Deadman Lake
LF
BLF
Dish Hill
1999 M7.1
HVF
LLF
1992 M7.3
San Andreas Fault
Los Angeles

Figure 1. [Bernard and Behr, 2017]
Major faults of the Dish Hill region

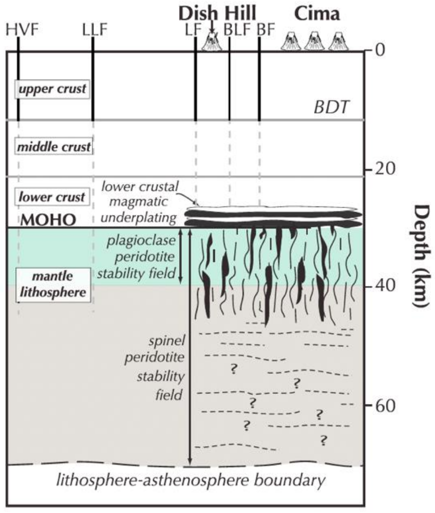

HVF
LLF
Dish Hill
LF
BLF
BF
Cima
0
20
40
60
Depth (km)
upper crust
BDT
middle crust
lower crust
lower crustal magmatic underplating
MOHO
plagioclase peridotite stability field
mantle lithosphere
spinel peridotite stability field
?
lithosphere-asthenosphere boundary

Figure 3. [Bernard and Behr, 2017]
Schematic cross section (green line on map) through the Cima and Deadman Lake fields

What is a mantle xenolith?

- **Fragments of the Earth's mantle** (Figure 4)
- **Transported to the surface via volcanic rocks**

A "xenolith" is a piece of rock within an igneous rock that did not derive from the same magma as the host rock but came from elsewhere (usually the surrounding country rock)

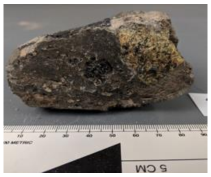


Figure 4. [Bates and Bender, 2019] Dish Hill mantle xenolith

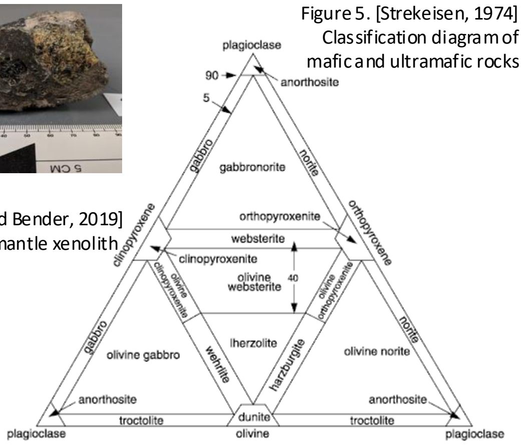

plagioclase
90
5
anorthosite
gabbro
norite
gabbronorite
orthopyroxene
clinopyroxene
websterite
clinopyroxenite
olivine websterite
40
olivine clinopyroxenite
olivine orthopyroxenite
orthopyroxenite
gabbro
olivine gabbro
wehrlite
lherzolite
harzburgite
olivine norite
norite
anorthosite
anorthosite
dunite
troctolite
troctolite
plagioclase
olivine
plagioclase

Figure 5. [Strekeisen, 1974] Classification diagram of mafic and ultramafic rocks

Why are they important?

They capture the the mantle beneath that region during the time of eruption. However, some limitations of mantle xenoliths are 1) we cannot observe the field relations, 2) mantle xenoliths are often small which makes it hard to estimate the bulk composition, and 3) interaction with the host magma often complicates their chemistry. Yet, mantle xenoliths are extremely valuable in that it is a directly samples the mantle in our place. Which enables us to study the chemistry and the rheology of mantles even in areas where it is not tectonically exposed (e.g., ophiolites).

Petrography of Dish Hill xenoliths

Bernard and Behr 2017 grouped them into three groups:
One **sourced from the lithospheric mantle**

1) **Cr-diopside group** of *spinel peridotites* and *pyroxenites*

And two **sourced from the lower crust and crust-mantle transition zone** (some, in a strict sense would be a lower crustal xenolith)

2) **Green-pyroxene group** of *websterite, two-pyroxene gabbro,* and *two-pyroxene micro gabbro*
3) **Al-augite group** of *clinopyroxenite, websterite, olivine micro gabbro,* and *one-pyroxene gabbro*

Among these, the first group is the predominant group and others are subordinate. (For rock type details see Figure 5)

Things the xenoliths tell us

Mantle structure beneath the Mojave [Luffi et al., 2009]

Thorough geochemical and isotopic analyses of Dish Hill xenoliths, we could see that the Mojave lithosphere is compositionally layered. The upper part of the lithospheric mantle is ancient, refractory, and depleted in radiogenic Nd, representing remnants of the North American cratonic mantle. The lower part is a younger, more fertile layer enriched in radiogenic Nd, interpreted as the Farallon oceanic lithosphere attached during flat-slab subduction. (Figure 6)

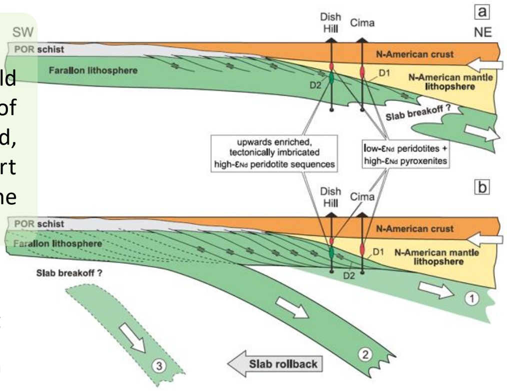

a
SW
Dish Hill
Cima
NE
POR schist
Farallon lithosphere
N-American crust
D1
D2
N-American mantle lithosphere
Slab breakoff ?
upwards enriched, tectonically imbricated high-εNd peridotite sequences
low-εNd peridotites + high-εNd pyroxenites
b
Dish Hill
Cima
POR schist
Farallon lithosphere
N-American crust
D1
N-American mantle lithosphere
D2
Slab breakoff ?
1
2
3
Slab rollback

Figure 6. [Luffi et al., 2009] Cartoon of rebuilding the Mojave lithosphere by underplating Farallon slab: diagram cross sections illustrating possible mechanisms of oceanic mantle addition to the thinned Mojave lithosphere during Farallon subduction

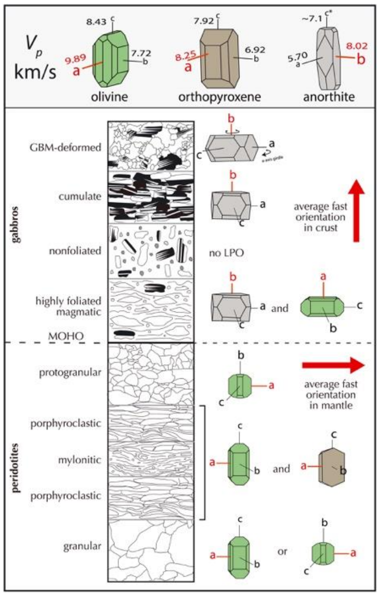

V_p km/s
8.43 c
9.89 a
7.72 b
olivine
7.92 c
8.25 a
6.92 b
orthopyroxene
~7.1 c*
5.70 a
8.02 b
anorthite
gabbros
GBM-deformed
cumulate
nonfoliated
highly foliated magmatic
MOHO
no LPO
and
average fast orientation in crust
peridotites
protogranular
porphyroclastic
mylonitic
porphyroclastic
granular
and
or
average fast orientation in mantle

Figure 7. [Bernard and Behr, 2017] Seismic fast axes for the LPO-producing minerals shown at the top of the figure. Bottom is the seismic anisotropy patterns emerging in lower crust and upper mantle xenoliths. LPOs recorded in lower crustal fabrics result in plagioclase and olivine fast axes oriented vertical to foliation (in this figure foliation is assumed to be horizontal). LPOs recorded in upper mantle olivine and orthopyroxene result in a fast axes oriented parallel to foliation.

Deformation and rheology of the Mojave lithosphere [Bernard and Behr, 2017]

Deformation fabrics of the xenoliths from Dish Hill along with Cima, show that the upper mantle beneath the Mojave show strong lattice-preferred orientations (LPOs) that generate seismic anisotropy. The various deformation fabrics observed from near Moho depths under the two regions reflects significant heterogeneity in their Mojave source region. Moreover, the fast axes of the mantle and lower crustal xenoliths were orthogonal, which means their anisotropies can appear anticorrelated in seismic data across the Moho, even if the two layers were kinematically linked. (Figure 7)

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5.14 (14) Mojave Irrigation

Irrigation and Farm Closures along the Lower Mojave River

Ben Reynolds

The history of agricultural development followed by abandonment and re-desertification in the downstream reaches of the Mojave River watershed is emblematic of water development in the arid Western half of the United States. The small-scale nature and hydrologic setting of this watershed caused this course to be ran rapidly compared to the agricultural epicenters that make the news. The story should serve as a warning to the massively productive basins confronting the same issues.

An Extremely Brief History of Western US Groundwater Development

The author Wallace Stegner popularized the 100th meridian as the dividing line between the US east and west. This line, which runs through the Dakotas, Nebraska, Kansas, Oklahoma, and Texas, nearly coincides with the 20 in/yr isohyetal marking the boundary between having enough rainfall for agriculture and requiring irrigation. In satellite imagery, the zone of this boundary appears as a shift from rectangular fields of crops to round ones. These round fields result from the invention that made groundwater-irrigated agriculture require far less work, center pivot irrigation (Evett et al., 2020). Before this device, windmill driven wells allowed western farmers and ranchers to pull up enough water for livestock and small gardens. Having enough water to grow crops like wheat and alfalfa, however, still required surface water sources channeled through canals. This limitation began to change as combustion and electric motors were developed and used to run well pumps. Profitability was still hampered, however, by the intensive labor needed to move irrigation pipes around the large fields necessary to grow grains. A Colorado farmer changed this in 1948 with the invention of center pivot irrigation. In this design, water pumped from a well with an electric or combustion motor runs along a series of spans (truss bridges) with sprinklers. The critical innovation was using the pressurized water to drive wheels supporting the spans causing them to rotate about the pivot. Since the 1940s, irrigated farmland acreage in the US has more than doubled and about a third of this acreage uses center-pivot irrigation (Evans, 2001). This development sometimes comes at the cost of depleted aquifers, and satellite imagery of towns around the Mojave river shows the faint concentric circles of center pivot irrigation's wheel tracks but nothing green except encroaching desert shrubs.

The Mojave River Watershed

The Mojave River runs north/northeast from the San Bernardino mountains through the towns of Victorville and Barstow before draining into the dry East Cronese and Soda Lakes. Apart from a few reaches where the water table intersects the river bed, the Mojave is a perennial river that only has flowing water following precipitation events (Lines, 1996) (Fig. 1). The river connects to and has rapid interchange with the floodplain aquifer, which has limited connection to the regional aquifer (Stamos et al., 2002) (Fig. 2). Because of this, groundwater extraction causes rain from precipitation events to infiltrate more and flow down the river less. This response reduces downstream infiltration preventing groundwater recharge.

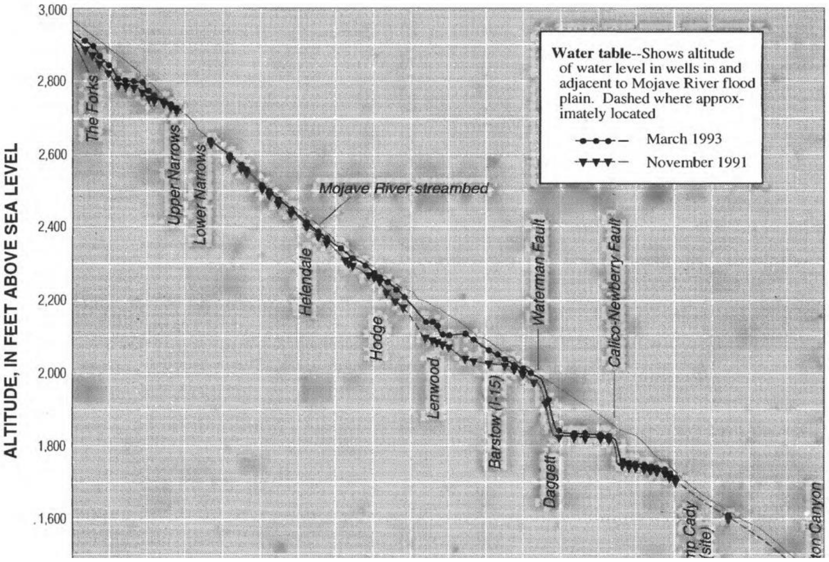

Figure 1: River bed and water table heights before and a after a flood event from Lines (1996).

Irrigation Using the Floodplain Aquifer, Water Disputes, and Farm Closures

Following the nation-wide trend of irrigation after World War II, groundwater extraction from the floodplain aquifer grew from 30,000 acre-ft/yr in the 1930s to 100,000 acre-ft/yr in the 1950s and has stabilized since the 1960s at about 120,000 acre-ft/yr (Lines, 1996). This extraction caused many river reaches that used to have consistent groundwater seeps to go dry (Lines, 1996). In 1990, downriver water users initiated a lawsuit against upriver users as it had become clear that recharge was not adequate to continue extraction at the historic level (McClurg & Sudman, 2000). This lawsuit was significant not only because it would determine which farmers win and lose, but also because it was to some degree a challenge to west's longstanding principal of "first in time, first in right." This principal was borne of water's use for mining operations and holds that the first individual or company to make "beneficial use" of a water resource has a right to the resource with priority corresponding to when beneficial use was established. Under this principle, when a water resource diminishes, later users would go fully dry before earlier users are required to make any reductions in consumption. The issues with this principle, given a city with millions of people may have relatively junior water rights, are obvious. The alternative, termed "equitable apportionment", would see all users reduce consumption in times of low supply. Equitable apportionment won out in the 1998 court ruling, but this ruling did not stand. Upstream water users with senior water rights appealed to the California supreme court, which ultimately overturned restrictions on their water use in 2000. Most of the farms on the downstream reach in Mojave valley east of Barstow have shutdown in the years since this decision, as can be seen from land use maps (Figure 3). While I was unable to find a direct causal link, the maintenance of upstream users' full allocations seems probable to have been a factor.

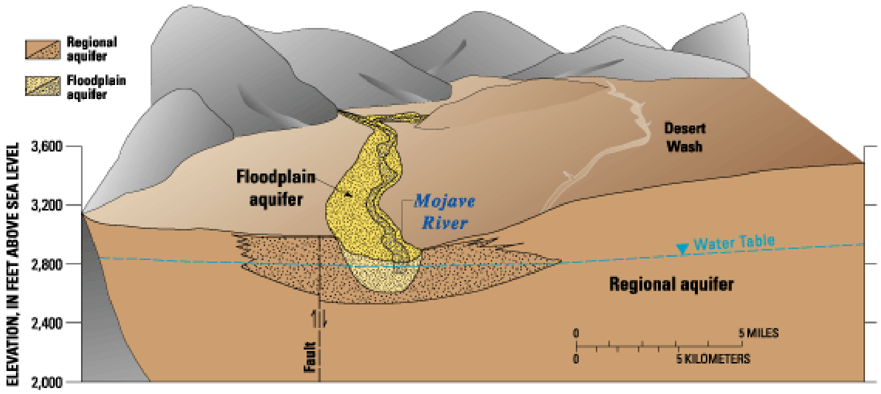
Regional aquifer
Floodplain aquifer
ELEVATION, IN FEET ABOVE SEA LEVEL
3,600
3,200
2,800
2,400
2,000
Floodplain aquifer
Mojave River
Desert Wash
Water Table
Regional aquifer
Fault
0
5 MILES
0
5 KILOMETERS

Figure 2: Conceptual Diagram of the Mojave River Watershed's Aquifers from Stamos et al. (2002).

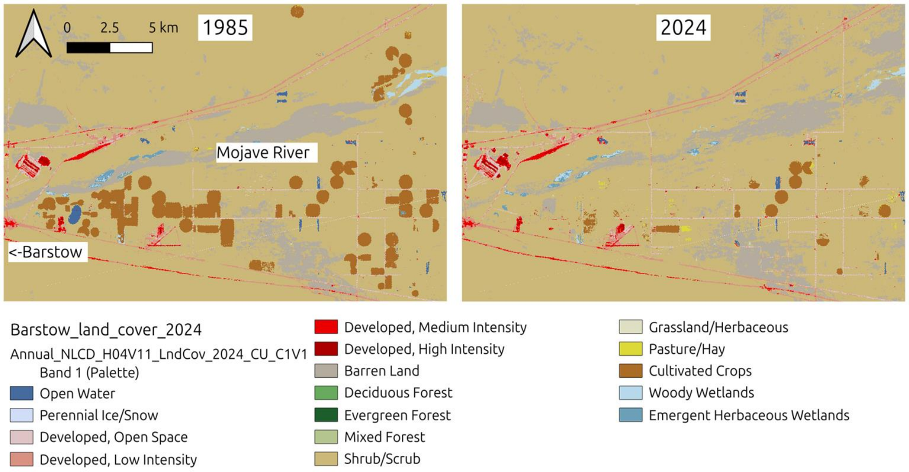
0 2.5 5 km
1985
Mojave River
<-Barstow
2024
Barstow_land_cover_2024
Annual_NLCD_H04V11_LndCov_2024_CU_C1V1
Band 1 (Palette)
Open Water
Perennial Ice/Snow
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands

Figure 3: National land cover database classification in the Mojave Valley in 1985 and 2024.

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Evett, S. R., Colaizzi, P. D., Lamm, F. R., O'Shaughnessy, S. A., Heeren, D. M., Trout, T. J., et al. (2020). Past, Present, and Future of Irrigation on the U.S. Great Plains. *Transactions of the ASABE*, *63*(3), 703–729. https://doi.org/10.13031/trans.13620

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Stamos, C. L., Martin, P., & Predmore, S. K. (2002). Evaluation of artificial recharge in the Mojave River Ground-Water Basin, California. *Open-File Report*. https://doi.org/10.3133/ofr02430

5.15 (15) Early San Bernardino History

Early San Bernardino History:
Native Americans, Spaniards, Mormons, and Slaves

Korbi Thalhammer

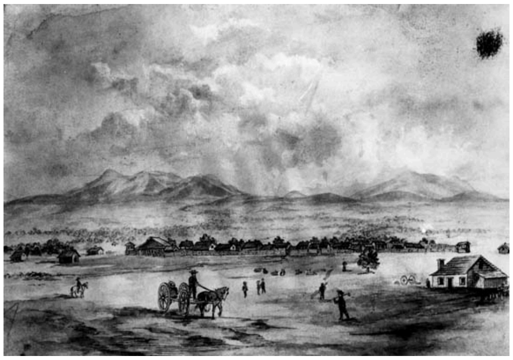
Native Americans, the Mission Period, and Early White Settlers

Serrano Indians have inhabited the modern San Bernardino Valley since at least 1000B.C.E. The first Spaniards arrived in the area in the early 1770s, and included Juan Bautista de Anza's far-ranging expedition, but no Western settlement was established until the early 1800s. The name San Bernardino is traditionally attributed to Franciscan priest Padre Francisco Dumetz who traveled into the valley on the feast day of San Bernardino of Sienna in 1810. The same year, a small waystation named Politana was established among the Indian settlements on modern Bunker Hill as a stopping point for Spanish travelers from the Spanish province Sonora (now the state of Sonora in modern Mexico).

In 1819, Mission San Gabriel established an estancia in what is now Redlands as a place to raise sheep and cows for the mission. When the missions were decommissioned by the newly independent Mexican government in 1833, several prominent Mexicans tried to acquire the estancia as "Rancho San Bernardino." By 1842, Antonioa Maria Lugo and his sons and nephews had won the right from the Mexican government to graze several thousand cattle in the San Bernardino Valley, and their presence encouraged new settlements in what is now San Bernardino and along the Santa Ana River near modern Redlands.

In 1851 (California was only a year old) Mountain Cahuilla Indians, who had been recruited since 1822 by Mexican colonists to help guard their herds against bandits, pursued and killed 11 of the 12 members of the infamous Irving Gang in San Timoteo Canyon. Although the killing was officially sanctioned even in the newly formed U.S. state, newly arrived American settlers misunderstood the killing of white men by native people as the start of a revolt against white settlers and called for troops from the Presidio of San Diego. The Mountain Cahuilla fled to the San Jacinto Mountains to escape the troops, who were eventually called off by Major General Joshua Bean (who learned the truth) before committing any violence.

Mormons in San Bernardino



Also in 1851, Antonio Lugo, the original holder of Rancho San Bernardino, sold 40,000 acres to several members of the Church of Jesus Christ of Latter Day Saints (Mormons) for $77,000 (about $3.2 million today). Broadly, the Mormon town of San Bernardino, incorporated in 1854, was a portion of Brigham Young's ongoing efforts to provide food and immigration access between Southern California and existing Mormon settlements in Utah. The existing mile square grid system in San Bernardino was based on the streets of Salt Lake City.

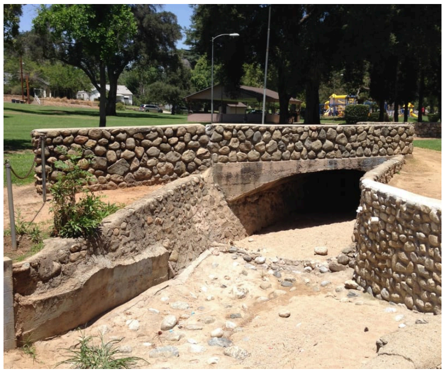
Many of the original San Bernardino Mormons were members of the Mormon Battalion, which was an Infantry unit composed entirely of Mormon volunteers who marched nearly 2,000 miles from Iowa to Utah during their service in the Mexican American War (1846-48). This "service" was arranged by Mormon leaders lobbying the federal government for financial assistance to flee west from violent persecution in Illinois. The attachment of the Mormon Batallion simultaneously served the government's purpose of ensuring the disgruntled sect did not independently rise against the United States during the ongoing war with Mexico. No other United States military unit has ever been uniformly religious or borne a religious designation.

In 1857, Brigham Young recalled the Mormon settlers from San Bernardino, precipitating a mass exodus and the economic collapse of the town as settlers rushed to sell their property to raise funds for the journey back to Salt Lake City. Some disagreement exists regarding the reasons for Young's decision to abandon the San Bernardino settlement, but generally the motives likely included the clash with U.S. troops known as the Mormon Rebellion or the Utah War, as well as Young's persistent fear that San Bernardino might undermine the success of the Mormon establishment in Salt Lake City by drawing settlers to Southern California, known for better agricultural and economic opportunity.

Slavery in San Bernardino

Several of the Mormon settlers who arrived in San Bernardino brought slaves with them from Utah. California was admitted to the United States as a free state as part of the Compromise of 1850, so all enslaved people should, legally, have been freed upon arrival in the state. But slave owners like Robert Smith relied on the remoteness of the San Bernardino settlement and the illiteracy of their slaves to keep them ignorant of their freedom.

One of Smith's slaves, Biddy Mason, eventually earned her freedom in 1856 when Smith neglected to appear at a court hearing after falsely claiming that Mason wanted to leave with him for Texas (where slavery was still legal) and then bribing Mason's lawyer to abandon her case. Nearly four years after her freedom hearing, Mason finally received papers reflecting her freedom. Once free, Mason moved to Los Angeles with her children and became a prominent businesswoman, first working as a nurse and midwife and eventually earning enough money to become one of the first Black landowners in the city. Mason started a school for Black children and played a major role in the founding of the city's first Black church, the First African Methodist Episcopal Church of Los Angeles, which remains active today. A park in downtown Los Angeles is dedicated to Mason's memory and legacy.



Mill Creek Zanja (aka "Sankey"), dug in 1819 by Serrano Indians to provide water to their farms at Gauchama Village (present day Loma Linda). Water rights were tracked by the hour, and the consistent supply led to an agricultural boom, including major production of oranges in present day Redlands. Today, the Zanja is preserved as a greenway.

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7. https://en.wikipedia.org/wiki/Biddy_Mason

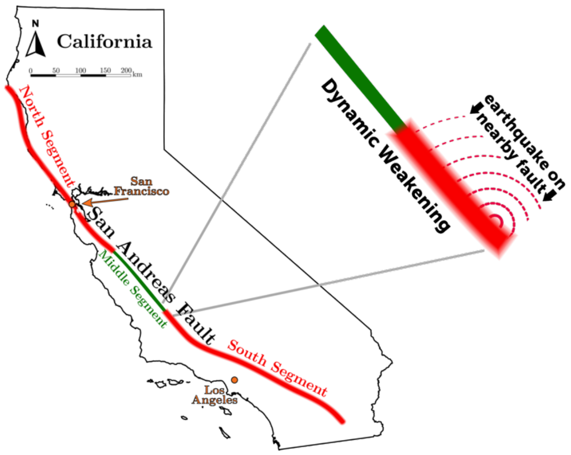
5.16 (16) SAF Gouge and Slip Rates

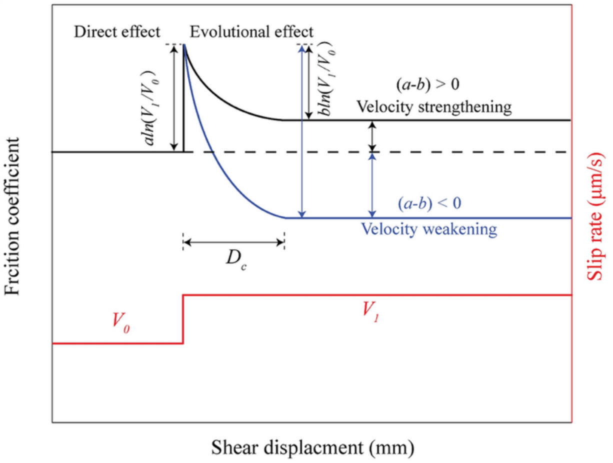
San Andreas Fault Gouge and Slip Rates

Victor Vescu · Ge136a · FT25 · Oct 24-26

Slip Rates:

The San Andreas fault accommodates roughly 2-3.5 cm of right-lateral slip every year, although its slip rate is distributed unevenly. Seismogenic segments accumulate up to 3.5 cm of strain every year, which is released as large earthquakes. Creeping segments exhibit steady, aseismic slip at up to 2.5 cm/year. This variation in slip behaviour has been linked with differences in frictional properties across the fault. Stick-slip regions of the fault have velocity weakening properties, meaning that the friction coefficient goes down as the slip velocity goes up right before an earthquake. Slow slip regions, have velocity strengthening behaviour, meaning that any increase in sliding velocity also increases the friction on the fault. The slip rate during an earthquake is also controlled by dynamic weakening mechanisms, such as thermal pressurisation of pore fluids.





Fault Gouge:

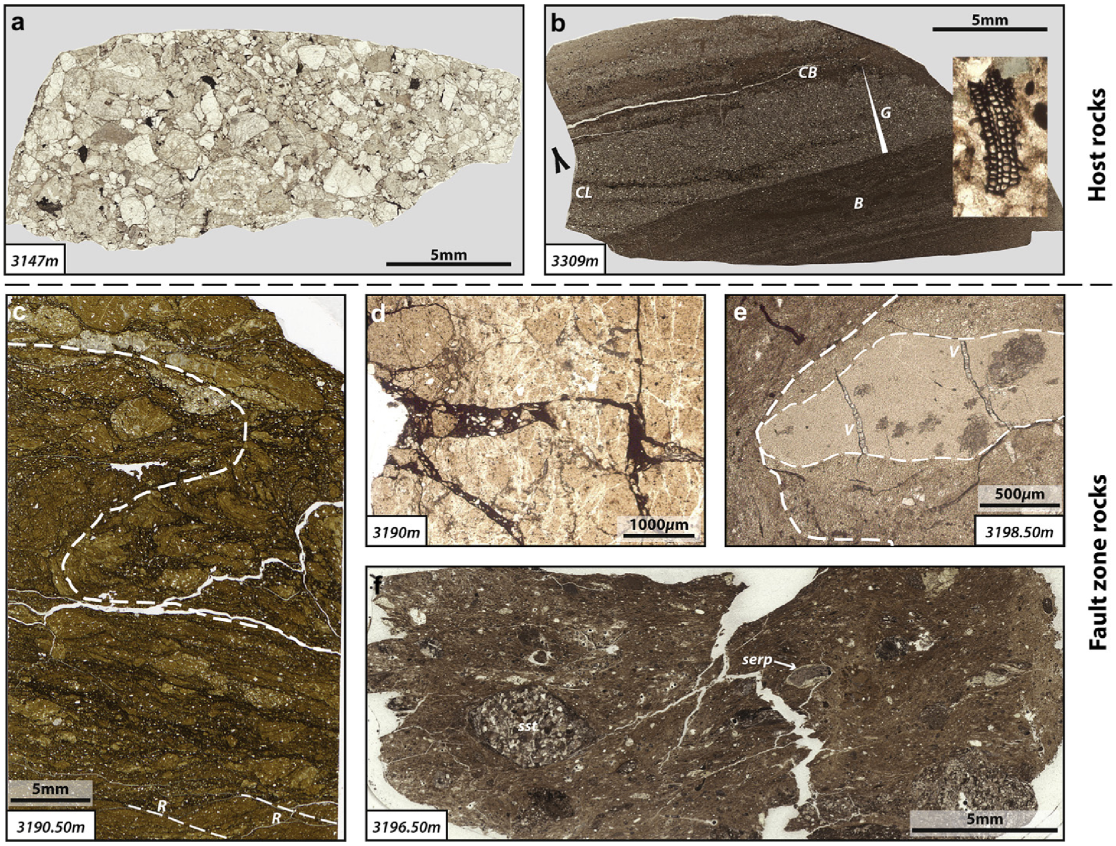
Fault gouge is the ultrafine, clay-rich material generated by repeated shearing and grinding of the wall rocks. It is found within the principal slip zone of the fault. Gouge composition is partly determined by the host rock, and surrounding fluids and fault zone depth can impact its fabric as it matures and changes its mechanical properties. Fault gouge is extremely fine-grained, with particles that are usually less than 1 micron. The friction coefficient of fault gouge is as low was 0.1 to 0.3. Gouge generally contains minor amounts of feldspar, calcite, and graphite. The gouge of the San Andreas has been studied by the San Andreas Fault Observatory at Depth (SAFOD), which has recovered samples that fall into two types:

1. **Smectite-rich fault gouge is dominated by clays that swell when they absorb water and has a highly layered structure.**

2. **Serpentine-rich fault gouge result from hydrothermal alteration of ultramafic rocks, and contains hydrous minerals such as lizardite and saponite.**

Connections between gouge and slip rates:

As the material that experiences the most shearing within the fault zone, studying gouge is crucial to explaining the frictional behaviour of fault regions. Laboratory experiments performed on SAFOD samples have shown a strong correlation with the composition of the gouge. (i) Gouges that are rich in phyllosilicates such as smectite, talc, and serpentine tend to increase their friction with slip rate, promoting stable sliding and sustained creep. This is found in the central creeping section of the San Andreas and has very high ductility and a low base friction coefficient. Elevated fluid pressures reduce effective normal stress and can shift a velocity-strengthening gouge toward instability. (ii) Gouges that are heavy in quartz and illite generally decrease their friction with slip rate, favoring instability and earthquakes. This type of gouge, found along the southern and northers segments of the San Andreas, is more brittle and has a higher base friction coefficient. Fine grained clays typically have extremely low permeability and do not allow easy fluid diffusion away from the fault. Thus, pressure can quickly build up during shear heating.



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5.17 (17) Vertebrate Fossils of Lake Manix

Hannah Way
Ge 136
Fall 2025

Field Guide to the
Not-So-Recently Deceased:

Vertebrate fossils of Plio-pleistocene Lake Manix

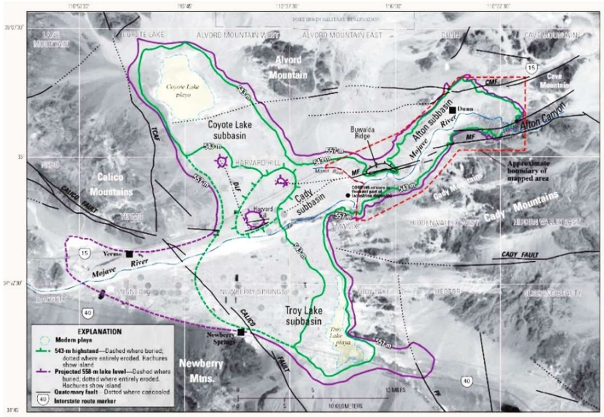

Figure 1. Map of Manix basin region with Pleistocene lake highstands overlain. From Reheis et.al.

Geological Background

The Pasadena Orogeny converted the region from a mostly flat plain to a series of ridges and valleys, constraining the Mojave river to a specific trough. A layer of fanglomerate material deposited in the interglacial period that followed is believed to have contributed to damming of the basin and the subsequent formation of the lakes.

Lake Manix is understood to have existed as three distinct lake phases. The first lake was the shallowest and consisted of a cluster of lakes constrained to their respective subbasins. After drying out through a yet-unknown mechanism, a period of heavy rain resulted in the formation of the second, much deeper lake. At this time the subbasins coalesced and the lake overtopped the Buwalda sill, spilling into Afton subbasin and reaching a highstand of approximately 558 m. Another cycle of drying and wetting formed the third and final lake. The shoreline of this lake is best preserved and indicates a highstand of 543m. Lake 3 eventually drained through Afton canyon and formed Mojave lake, thus ending Lake Manix's time as the terminus of the Mojave river.

Fossil Fauna

Birds

Over 60 bird fossils have been recovered from Lake Manix. Most are extant species, and all are waterfowl associated with shallow, still waters (or predators that feed on waterfowl). Further, many are migratory in nature. This suggests that Lake Manix may have functioned as a stopover for birds traveling through the region, as the modern Mojave river does today. These bird fossils are found primarily in the strata associated with lake 1, supporting its characterization as a shallow and brackish body of water. The Oregonian Fossil Lake contains a very similar group of bird fossils, making it an excellent analog for Lake Manix. Three species of birds found at Lake Manix are now extinct. Two specimens are attributed to flamingo species, the smaller identified as *Phoenicopterus minutus* and the larger as a juvenile *Phoenicopterus copei.* The presence of a juvenile intimates that *P. copei* may have nested at Lake Manix. Finally, the large stork species *Ciconia maltha* (originally discovered in the La Brea tar pits) was also found in Lake Manix strata. The identified species are listed below and brief descriptions of each are included.

Aechmophorus occidentalis, Western Grebe
A large black and white waterbird with a long neck, long straight bill, and red eyes.

Pelecanus erythrorhynchos, American White Pelican
A huge white waterbird with a long neck and large orange bill.

Phalacrocorax auritus, Double-Crested Cormorant
A gangly black fishing bird, relatives of frigatebirds.

Ciconia maltha, Asphalt Stork
An extinct stork species identified at the La Brea tar pits.

Phoenicopterus copei, Copes Flamingo
A large extinct species of flamingo.

Phoenicopterus minutus, Flamingo
A small extinct species of flamingo, believed to be the smallest when discovered at Lake Manix.

Branta canadensis, Canada Goose
A large ground forager with a black neck and signature white chinstrap.

Aythya vavalisineria, Canvasback Duck
A rusty red-headed duck with a sloping forehead and red eyes. This bird dives for aquatic plants.

Oxyura Jamaicensis, **Ruddy Duck**
Small, blue-billed duck with large upright tail feathers. This bird dives for aquatic invertebrates.

Aquila chrysaetos, **Golden Eagle**
A very large brown raptor with a golden nape.

Grus pallas, **Whooping Crane**
A very tall and long-legged white bird with a red crown and black face and wingtips.

Fulica americana, **American Coot**
A chickenlike dark grey waterbird with a white sloping bill.

Haliaeetus leucocephalus, **Bald eagle**
A very large dark brown raptor with white head and tail.

Mammals

Mammals are less abundant, but undeniably present in the Manix beds. Most specimens were recovered from the lower beds associated with lake 1. At this time Lake Manix was a series of shallow basins surrounded by lowlands sporting abundant reedy vegetation. Consequently, many of the mammalian fossils belong to plain-dwelling herbivores such as horses, llamas, and camels. This led to the region being referred to as a "Haven for herbivores", despite no fossil plants being found. Carnivores are also present, though they are believed to have been initially excluded from the region by the hot and dry climate prior to the lake formation. The identified species are listed below and brief descriptions of each are included.

Canis latrans, **Coyote**
A light grey mid-sized canine.

Canis dirus, **Dire Wolf**
An extinct canine similar in size to the gray wolf, but with larger teeth and stronger bite force.

Tremarctotherium simum, **Giant Short-faced Bear**
An extinct large and long-limbed carnivorous bear with forward pointing feet that allowed it to run at over 40 MPH.

Machairodontinae, **Saber-toothed Cat**
An extinct subfamily of carnivorous felines. Contains many of the "Saber-toothed cats".

Mammuthus, **Mammoth**
An extinct, enormous, furry proboscidean with spiraling tusks.

Equus scotti, **Scott's Horse**
A small extinct horse species more closely related to modern horses than zebras and asses.

Haringtonhippus francisi, **Stilt Legged Horse**
An extinct species of horses, smaller and with thinner leg bones than modern horses.

Camelops hesternus, **"Yesterday's Camel"**
An extinct camel believed to have had a similar appearance to the modern dromedary camel.

Hemiauchenia macrocephala, **Big Headed Llama**
An extinct llama species with long limbs and a larger skull than other llamas.

Antilocapra americana, **Pronghorn**
An artiodactyl plain-dwelling herbivore, unique in its possession of both horns and antlers.

Bison bison bison, **Plains Bison**
The largest terrestrial mammal in North America. A large, furry bovine that grazes in herds.

Reptiles and Fish

In the Pleistocene era *Siphateles bicolor* were distributed across the Great Basin. As orogeny shifted the landscape some groups became isolated, leading to the development of multiple subspecies. The *Siphateles* specimens found in the Manix beds are understood to be the Mojave native species, meaning that an Owens-Mojave River connection must have been established prior to the formation of Lake 1. The presence of *Gopherus agassizii* specimens in early Lake 1 strata supports the conclusion that the region was hot and arid prior to the formation of lake 1. The identified species are listed below and brief descriptions of each are included.

Siphateles mohavensis, **Mohave tui chub**
A chunky fish with large scales. They are native to the Mojave river and listed as endangered.

Gopherus agassizii, **Desert tortoise**
A large and herbivorous tortoise species well adapted to digging and roaming desert washes and canyons.

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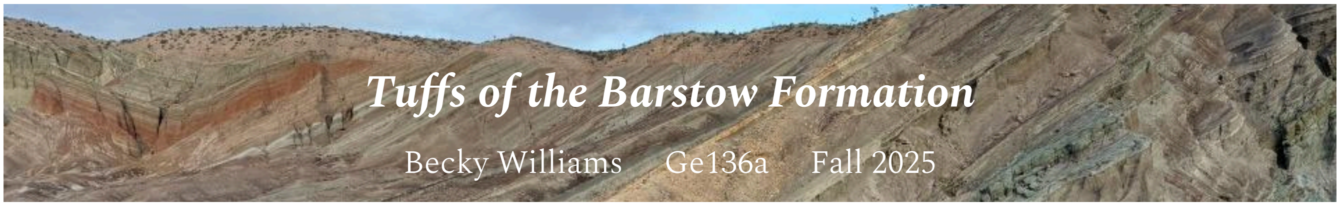
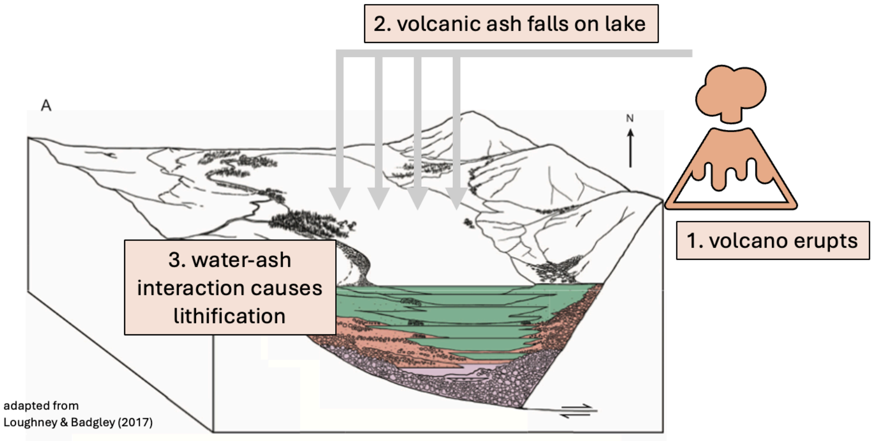
5.18 (18) Tuffs of the Barstow Formation


Tuffs of the Barstow Formation
Becky Williams Ge136a Fall 2025

The Barstow Formation is a sedimentary unit deposited ~19-13 Ma, during the Miocene. It consists of 6 facies that (broadly speaking) go from conglomerate-, to sandstone-, to mudstone-dominated, interpreted as recording a changing environment from alluvial fans (high-energy) to lakes and wetlands (low-energy) [3]. A syncline runs through the middle of the formation, and some layers outcrop on either side of the syncline. Mammalian fossils (both bones and footprints), including for camels and horses, have been found in the formation, and these fossils help define the Barstovian North American Land Mammal Age. The Barstow Formation is also notable for containing many tuffs, ranging in thickness from a few centimeters to 1-2 meters. Around 24-18 Ma [1], the Mojave desert region experienced extension, which thinned the crust, decreasing pressure and causing magma to melt. As a result, there was quite a lot of volcanism during the Miocene, producing volcanic ash that has since lithified into tuff.

What is a tuff?

When ash from a volcanic eruption deposits on a landscape, under the right conditions that ash lithifies, forming a rock known as "tuff". Volcanic ash is high in silica and aluminum, both of which are highly soluble in high pH environments. Water fills in the pore spaces, dissolving the silica and alumina grains. From this solution, minerals precipitate out lithifying the ash into tuff. In the depositional environment of the Barstow Formation, which likely consisted of a saline, alkaline lake, the most common minerals to form were zeolites and potassium feldspar [6]. The minerals that form depend on both the composition of the volcanic ash and the composition of the water in the lake. As a result, variations across the lake affect the mineralogy of tuffs (e.g., ash deposited at edges of lake interacts with fresher water than ash deposited in the center of the lake) [2].


2. volcanic ash falls on lake
A
N
1. volcano erupts
3. water-ash interaction causes lithification

adapted from Loughney & Badgley (2017)

What can we learn from tuffs?

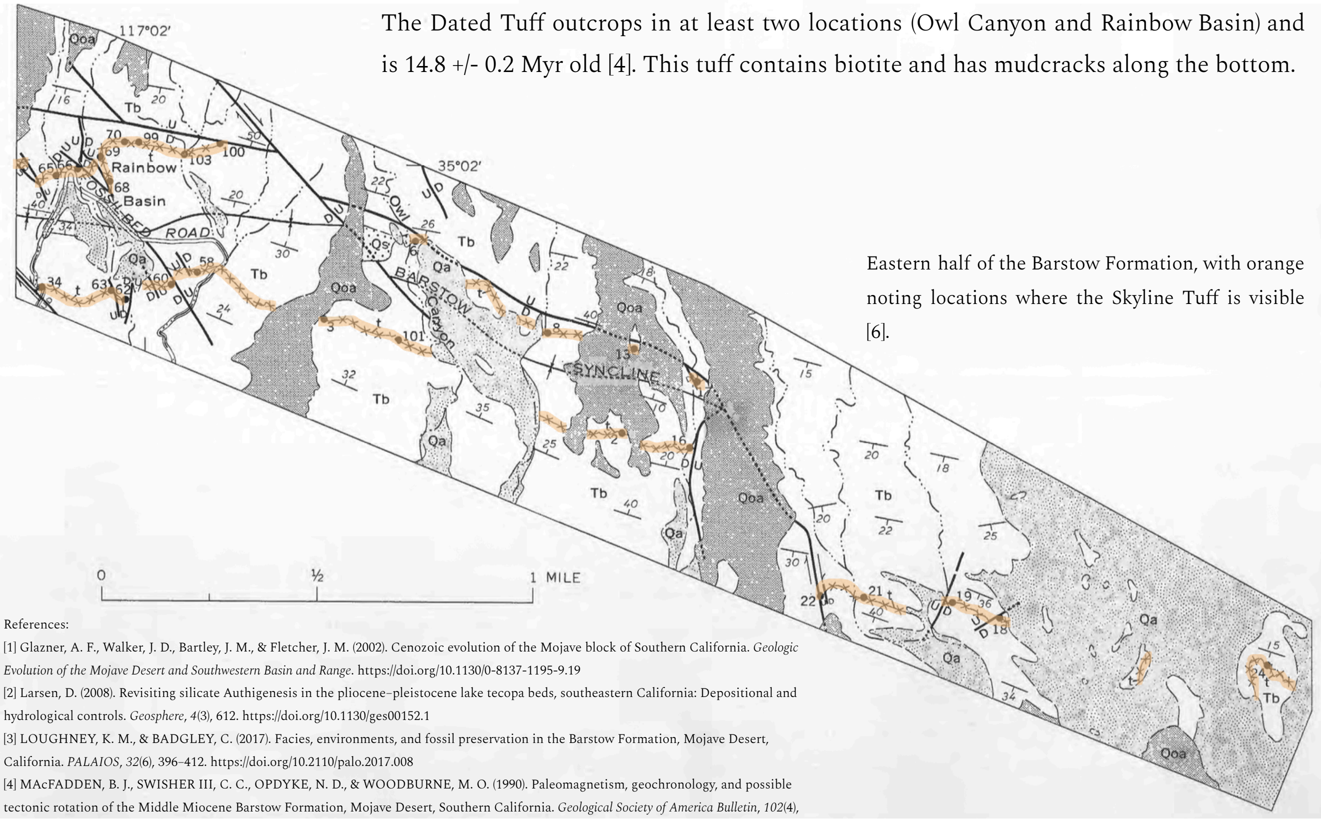
Tuffs, being igneous in origin, can be radiometrically dated. In sedimentary units, the presence of tuffs is extremely helpful for constraining the age of the other layers in the unit, inferring depositional rates, and, in the case of the Barstow Formation, providing age constraints on fossils and the North American Land Mammal Age. Biotite, feldspars, and hornblende contain potassium, which can be used for ^{40}K-^{40}Ar and ^{40}Ar/^{39}Ar dating. Both of these dating methods have been used to determine the ages of many of the tuffs in the Barstow Formation [4] .

Another benefit of tuffs is that, for a given tuff, the initial composition of the ash should have been effectively identical across the region. Therefore, variations in the present-day composition of the tuff reflect differences in the environment that the tuff has been exposed to since deposition. For example, water at the edge of a lake is typically fresher than water in the center of lake [2], so a tuff that lithified closer to the edge of the lake should reflect this variation in water composition. Additionally, processes since initial lithification can alter the mineralogy of tuffs. At the Barstow Formation, studies have shown that the Skyline tuff in Owl Canyon is much higher in potassium feldspar than tuffs elsewhere in the region [6]. One interpretation of this finding is that the tuff in Owl Canyon was in the central basin of a lake, where there were high concentrations of K^+ cations, particularly when lake levels were low [2].

Lastly, tuffs are (generally) easy to identify in the stratigraphy, as they are often bright white in color and may have distinct features such as mud cracks and/or lapilli. As a result, even without performing any laboratory analysis, tuffs can be traced across the stratigraphy to help correlate stratigraphic sections.

Notable Tuffs of the Barstow Formation

The most prominent tuff in the Barstow Formation is the Skyline Tuff, which is about 1-2 meters thick and outcrops at many locations across the entire region. This tuff contains lapilli, which are ~millimeter-scale tephra produced during volcanic eruptions (the other types of tephra are ash, which is <2 mm in size, and volcanic bombs, which are >64 mm in size). The Skyline tuff contains lapilli, suggesting that the volcanic center for that eruption must have been located nearby, since lapilli are larger than ash and cannot be carried as far as ash. One study suggests that lapilli do not travel more than a few kilometers from their volcanic centers [5].



The Dated Tuff outcrops in at least two locations (Owl Canyon and Rainbow Basin) and is 14.8 +/- 0.2 Myr old [4]. This tuff contains biotite and has mudcracks along the bottom.

Eastern half of the Barstow Formation, with orange noting locations where the Skyline Tuff is visible [6].

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